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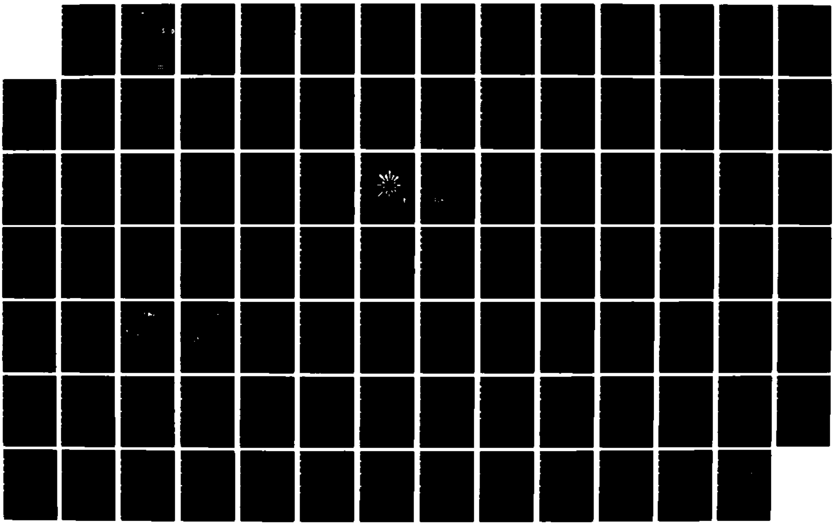

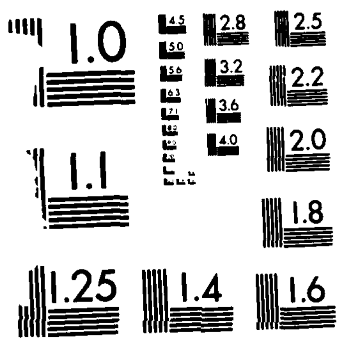

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FEASIBILITY STUDY FOR UTILIZING DREDGED MATERIAL FROM NORFOLK HARBOR DEEPENING FOR BEACH FILL

FORT STORY AT CAPE HENRY
VIRGINIA BEACH. VIRGINIA

BY

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DRAFT REPORT

FEBRUARY 1984

Prepared for:

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Investigation verifies that sand from designated dredging area in Thimble Shoal Channel is appropriate for disposal on eroded Fort Story beaches. Report deliniates promising areas for sand recovery within Thimble Shoal Channel and gives preliminary design recommendations for sand placement. Sand stockpiling at five sites was evaluated with limited data.

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FEASIBILITY STUDY FOR UTILIZING DREDGED MATERIAL FROM NORFOLK HARBOR CHANNEL DEEPENING

Excutive Summary

The results of this study indicate that it is feasible to use dredged material from Thimble Shoal Channel Deepening to fill eroding beaches at Fort Story. The eastern one-fourth of Thimble Shoal (Main) Channel above -55 feet MLW contains a continuous deposit of over two million cubic yards of quartz sand having about 1/4 millimeter diameter. An average of three miles to the southeast of this deposit, there is a one-mile stretch of eroded Fort Story beach. Net sand transport on this beach is alongshore, towards the west. Historical information and new data imply that the localized erosion is associated with a decreased supply of littoral drift from the Atlantic coast. Wave patterns and ebb tides have caused an extensive sand shoal to form slightly offshore of Fort Story's eastern boundary. Quantitative estimates substantiate that adequate material is available for constructing a beach fill. The fill will probably adjust to a foreshore slope of 1 on 15. The design berm elevation is +7 feet MLW. One million cubic yards of Channel sand will yield a minimum berm width (after reworking by waves) of 200 feet on presently eroded beaches. Prior to reworking, the maximum berm width may be as much as 450 feet on an eroded beach just after placement. Final engineering design with firm estimates of fill durability requires additional investigations to better define present conditions and diagnose local procedures.

In addition to beach fill, sand stockpiling has been addressed. Preliminary work indicates that 2.5 million cubic yards of material could be stored at five sites. Should a 55 foot project be authorized about 3.5 million cubic yards of sand would be dredged from the lower channel reach.

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PREFACE

This report summerizes engineering work performed to investigate the feasibility of using dredged material for beach fill on Fort Story Beach at Cape Henry, Virginia. The potential source of dredged material would be sediments in Thimble Shoal Channel made available through planned harbor deepening. The benefits derived through such utilization of dredged material appear to be profound.

This study and related engineering work was performed under Contract No. DACW-65-84-D-0054 by Waterway Surveys and Engineering, Ltd. (WS&E) for the Dredging Management Branch, Norfolk District, Corps of Engineers. The work was coordinated by Mr. Richard Klien, Project Mangeer.

The firm of Cyril Galvin, Coastal Engineer performed as a consultant and participated in both field investigation and engineering analysis.

This report was prepared by James W. Holton, Robert Hallermeier, Jonathan W. Lott and Cyril Galvin. The field work was carried out under the supervision of W. C. Holton, and technical engineering support was provided under the supervision of John Walsh.

FEASIBILITY STUDY FOR UTILIZING DREDGED MATERIAL FROM NORFOLK HARBOR CHANNEL DEEPENING

INTRODUCTION

This is a preliminary evaluation of the usefulness as beach fill of material to be dredged in deepening Thimble Shoal Channel within lower Chesapeake Bay. The particular shore segment considered here as recipient of fill is part of Cape Henry, Virginia, within Fort Story Military Reservation. The north-facing beach borders the main passage connecting Chesapeake Bay to the Atlantic Ocean, and the eastern portion of the beach is less than a mile from 10-fathom water depths. Figure 1 shows shorelines, selected hydrographic contours, and sites of interest near the Chesapeake Bay entrance.

Major sections in this report treat these topics: the *overall deepening project; advance engineering for dredging;* the extent and bottom characteristics within the most promising borrow site of Thimble Shoal Channel; topography and hydrography of the beach and nearshore zones in the Fort Story study area, according to previous work and 1983 field investigations; review of available enegineering and environmental data and presentation of computations required for an overview of coastal processes in the study area; documentation of design choices and quantitative results relating to beach fill at Fort Story using Thimble Shoal Channel material; and stockpiling of dredged material for future use. The final section summarizes conclusions on feasibility of the proposed engineering project, and lists recommendations for further work needed to develop a final project design.

A Beach Fill Plan has been prepared to reflect field data and the geometry of a recommended fill. The drawing supplements this report and is furnished separatly.

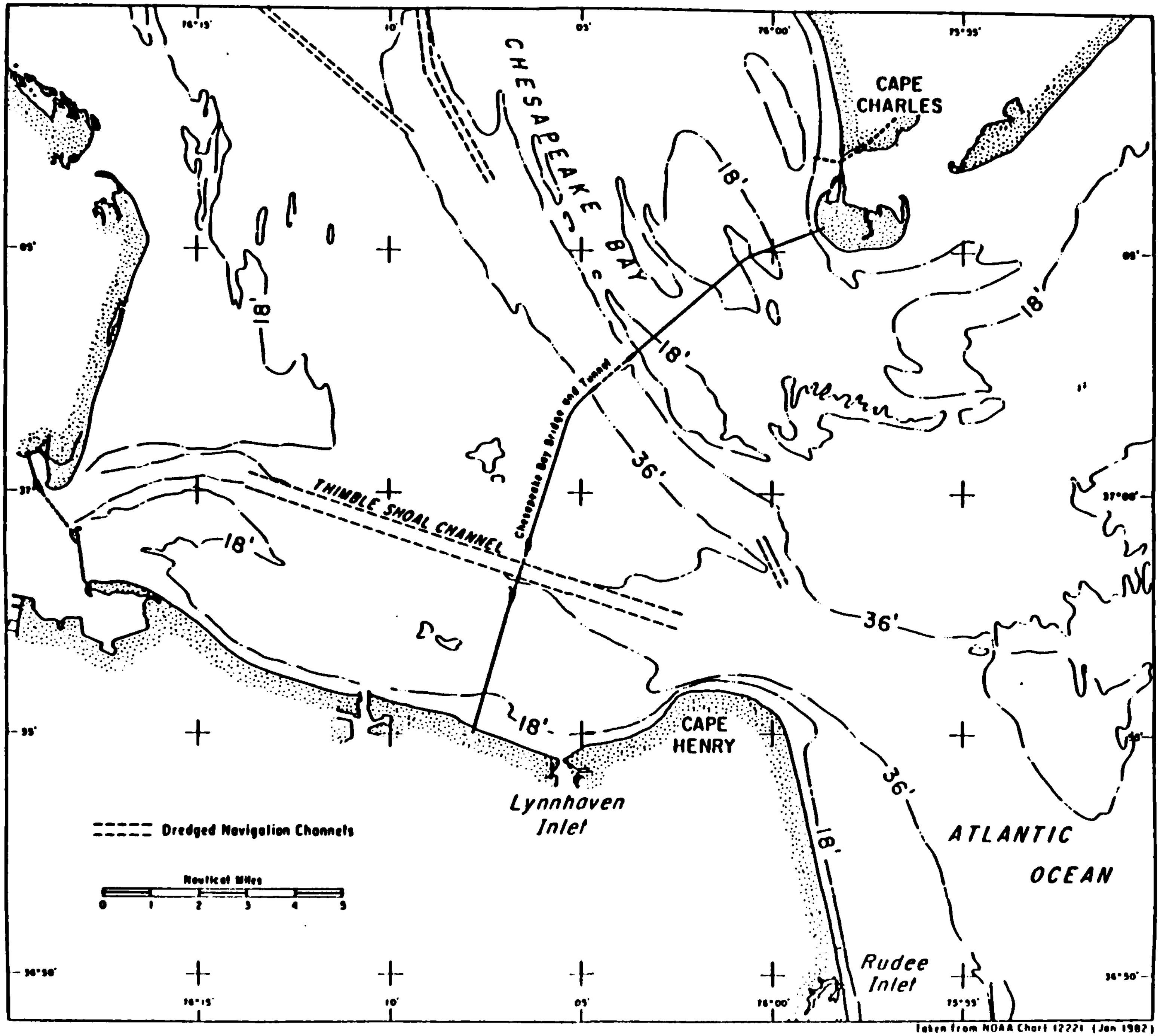

FIGURE 1. MAP OF CHESAPEAKE BAY ENTRANCE WITH NOTABLE SITES AND DEPTH CONTOURS

NORFOLK HARBOR DEEPENING

A compelling need has been demonstrated to deepen the harbor channels servicing Hampton Roads. This has been brought about by increases in world trade and the economics associated with using deeper-draft carriers. Currently, the Corps of Engineers is are giving detailed consideration to a 55 foot deep, full width project but is are also looking at phased dredging and lesser projects. For example, it may prove feasible to establish and maintain a 50 foot deep, full width channel as an interuim solution. This is mentioned because the ultimate scheme adopted will dictate disposal needs and will substantially impact any analysis of beneficial use of the dredged material.

Thimble Shoal Channel is but one segment of the overall deepening work. Dredging will have to be accomplished on inner harbor channels, and depending on the selected project, in ~~the~~ ocean channel.

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ADVANCE ENGINEERING FOR DEEPENING THIMBLE SHOAL CHANNEL

Dredging is the culmination of a series of engineering, social, economic, environmental and political needs and accomplishments without which a project of significance would not be conceived or completed. The purpose of the deepening project at hand is primarily to meet an economic need, but it is inexorably entwined with all of the above elements. A natural benefit which may be derived from the deepening is extensive utilization of a valuable resource - sand. The Thimble Shoal Channel, and potentially other channels, contains sediments of various character which may be used to mans benefit. This should not be overlooked on such a project as Thimble Shoal even though it is aside from the primary purpose of the project.

As mentioned before, several deepening options are in the advance engineering stage. Several of the options will necessarily provide for dredging of the downstream reach of Thimble Shoal which is relativily close to eroding beaches at Cape Henry. If this occurs, then it may present a unique opportunity to fill the eroding beaches by placement there of large quantities of dredged material.

Current engineering planning considers use of hopper dredges to be most viable in performing the dredging work. This is based on the assumption that the dredged material must be transported considerable distances to discharge sites. Local deposition of the material within reasonable distances from the channel would open up other dredging alternatives which might have economic significance. This is to say that the cost of dredging a particular channel reach, which is a function of dredged material transport distance, could sustain a quantum reduction by both reducing the transport distance and applying a different dredge-discharge configuration. Such a system might place dredged material directly on eroding beaches or land yet producing even further engineering, social, economic, environmental and political benefits.

This advanced engineering concept has extrodinary merit but must be tested. For example; pose the following questions:

Is there available material proximate to nearby shores?
Is this material suitable for beach or stockpile fill?
Is this material compatable with natural shore deposits?
What slope should the fill take?
Will it be durable?
Is material stockpiling feasible?

The first question concerning availability can be addressed by considering dredging options currently being planned. Should a 55 foot project be authorized then dredging will be required throughout the lower reach of Thimble Shoal Channel to depths sufficient to make available large quantities of dredged material.

Should a lesser 50 foot project be a reality, then certainly the available material would be reduced. Bottom elevations in this reach are on the order of -50 feet however navigation considerations must be taken into account. A recent report by Whitehurst (1983) outlines significant design parameters to consider in providing safe and efficient deep-draft navigation channels. Many of the parameters combine, particularly for Channels with ocean-wave exposure, to suggest dredging depths in considerable excess of a nominal project depth selected for less exposed channel reaches. This would be the case for lower Thimble Shoal Channel regardless of the nominal depth authorized. Therefore, it can be concluded material availability may not be a problem. It also appears reasonable to select a representative channel depth for a case study. A depth of -55 feet seems to be a reasonable point of reference since it falls between 50 foot and 55 foot projects taking into account the Whitehurst recommendations.

The remaining questions concerning the charater and application of the dredged material must consider not only available information but new work accomplished for this single purpose. These questions are addressed in subsequent topics.

SEDIMENT BORROW SITE IN THIMBLE SHOAL CHANNEL

The distorted plan view of Figure 2 includes selected depth contours based on a 1981 survey of Thimble Shoal Channel. As discussed previously, project dimensions have not been firmed up so to facilitate analysis, a dredging depth of 55 feet will be considered. The remainder of this report investigates whether such dredged material contained in the 55 foot deep channel prism could be applied to nearby eroded shores as beach fill.

During June 1983, vibratory bottom cores were taken at 42 sites in the main and south auxiliary channel, with each disclosing roughly 15 feet of the uppermost sediments. Appendix A to this report summarizes interpretation and quantitative analysis of these core data. The overall conclusion of this analysis is that near-surface sand prevails only in the easternmost one-fourth of the main channel (the shaded region indicated on Figure 2), where dredging will yield appreciable quantities of material usable as fill. Figure 3 presents a grain-size distribution composed from available information to represent bottom materials above -55 feet MLW within the Figure 2 borrow area. In dredging that area to such depth, a simple estimate indicates recovery of at least two million cubic yards of quartz sand with typical grain diameters near 0.25 millimeters.

Core locations were roughly one-half mile apart. The near surface sediments logged were assumed to correlate among the cores and extend over the intervening areas. Despite this assumption, a fair amount of confidence can be placed in the minimum volume of two million cubic yards and grain-size values of about 0.25 mm for borrow material within eastern Thimble Shoal Channel. One reason for such

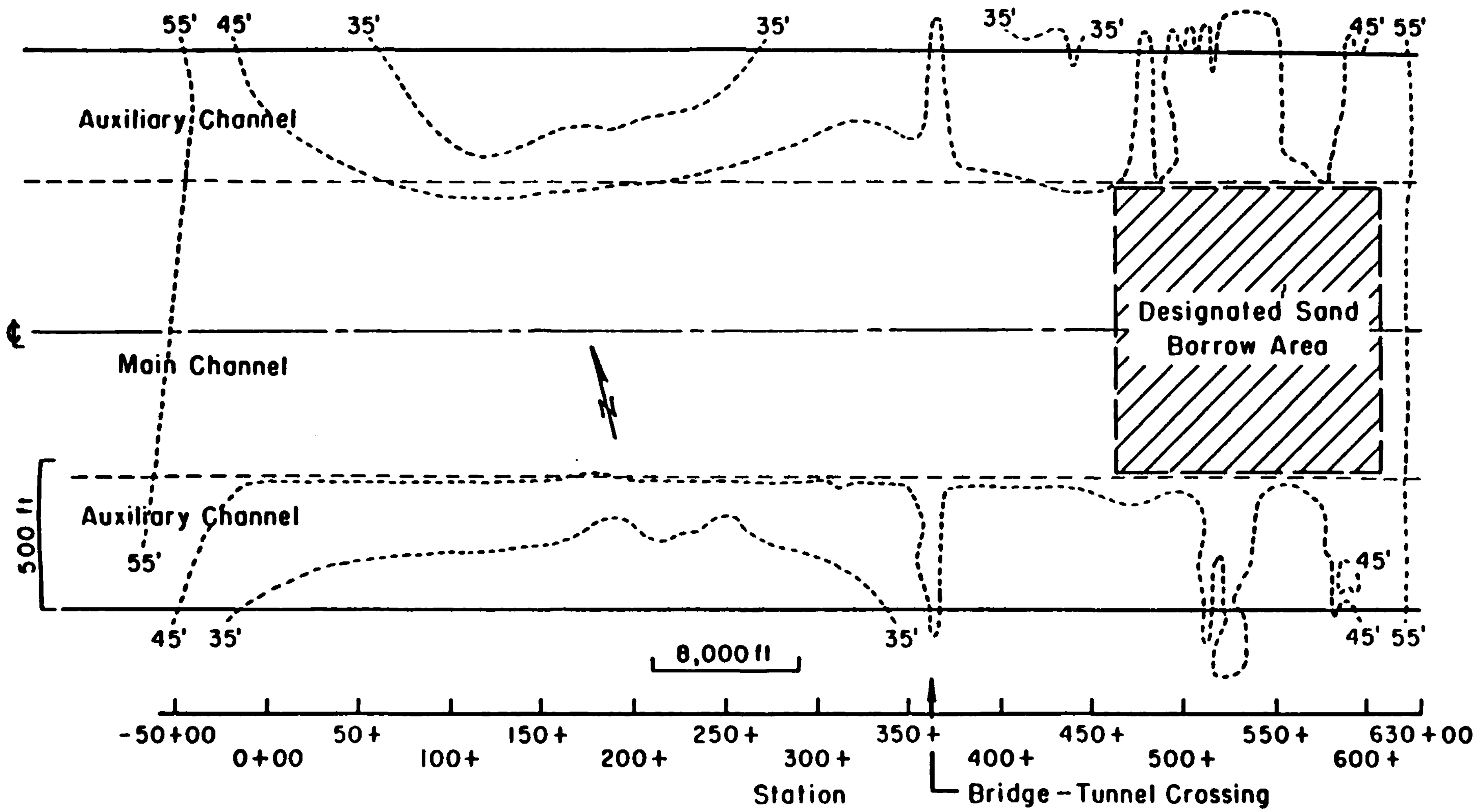
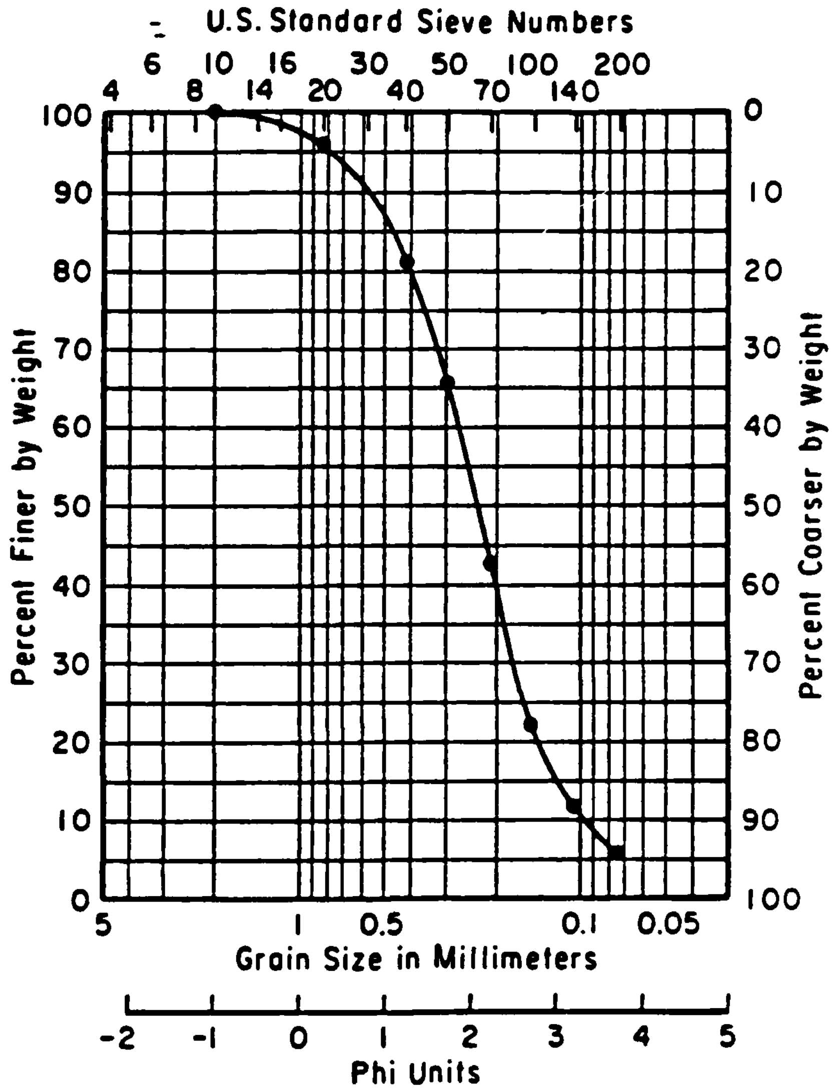


FIGURE 2. DISTORTED PLAN VIEW OF THIMBLE SHOAL CHANNEL WITH DEPTH CONTOURS FROM 1981 SURVEY, AND DESIGNATED BORROW AREA. (APPARENTLY CONVOLUTED CONTOURS NEAR EASTERN END INDICATE THAT AUXILIARY CHANNELS HAVE NOT BEEN DREDGED.)



COMPOSITE GRAIN-SIZE DISTRIBUTION FOR EASTERN THIMBLE SHOAL CHANNEL

FIGURE 3. CUMULATIVE SIZE DISTRIBUTION CURVE REPRESENTING DESIGNATED BORROW SEDIMENTS

confidence is the independent results reported by Meisburger (1972) on sub-bottom structure of the Chesapeake Bay entrance.

Meisburger (1972) analyzed marine seismic reflection profiles and sediment cores covering 180 square miles and nearly 2 x 10^9 cubic yards of sand between Cape Henry and Cape Charles. Concerning sand suitable for fill on nearby beaches, he concluded (pp. 38, 33) that

> "The most promising deposit crops out in Thimble Shoal Channel... This deposit is a coarse brown to reddish brown sand and gravelly sand (Unit E) ... The coarse, poorly sorted texture and absence of marine shells in most Unit E material suggest a fluvial origin and the heavy iron stains indicate subaerial exposure ..."

A total of about 19.4 million cubic yards of Unit E sand was estimated to be available either in exposure or under less than 5 feet of overburden, mainly in a narrow area of about one square mile extending fairly symmetrically about the axis of Thimble Shoal Channel eastward of the Chesapeake Bay Bridge-Tunnel crossing (Figure 16, Meisburger, 1972). However, those inferences about extent of suitable borrow material are based on only four cores taken within the eastern channel, and these cores appear to give conflicting evidence on the type of surface sediment (N20 and N21 vs. C34 and C44).

The 1983 core locations provide much denser information on channel bottom materials, with no apparent conflicts in indications about the Figure 2 borrow area. The type of sediment providing major weight to the composite sample of

Figure 3 appears to match fairly well with Meisburger's Unit E material in color and size descriptions: there are some 1983 mentions in field core logs of gravel and color stains (perhaps due to iron); the laboratory descriptions of sediment color are mostly "brown"; the predominant 1983 usage of "medium" from the Unified Soil Classification is equivalent to the Meisburger (1972) usage of "coarse" from the Wentworth Scale; and there is some overlap between 1983 grain-size distributions and typical Unit E sand analyses, although the latter samples tend to be coarser.

These matches, together with Meisburger's conclusion that Unit E sediment is a contiguous relict deposit, indicates that surface sand from eastern Thimble Shoal Channel can provide considerable beach fill. The exact suitability of dredged sand as nearshore material depends on size characteristics of the native beach sediment (Hobson, 1977).

CAPE HENRY COASTAL AREA

Previous Studies. A recent report by Everts et al. (1983) includes information on both historical and more remote shoreline movements at Cape Henry. Arcuate relic beach ridges within the present-day interior are evidence that "the Cape built northward and eastward". Historical shoreline movements in this vicinity provide indications opposite the prior trend: Figure 4 reproduces a portion of Map No. 43, showing that the north- and northeast-facing segments of Cape Henry have undergone appreciable retreat between 1852 and 1980, in terms of mapped locations of Mean High Water Lines.

Within the area represented in Figure 4, the overall trend in shoreline is slightly negative (erosion) from 1852 but surprisingly positive (accretion) in recent time (1962 to 1980). The variability in shoreline movements over space and time is summarized quantitatively by Everts et al. (1983), and provided here in Table 1. These data are average shore-normal rates of change in shoreline position, tabulated according to survey years and a one-minute grid of latitude/longitude. Only between the 1962 and 1980 surveys was there a consistent trend of shoreline movement over the four complete shore gridblocks displayed in Figure 4; even this case reveals pervasive shoreline advance solely in an overall sense, as there is mixed movement within individual gridblocks.

Near the central area of Figure 4, from 76°00' to 76°02' W longitude shoreline changes after 1916 appear to have been relatively small and of mixed direction. However, shoreline advance between each survey is appreciable in the flanking region to either the east or the west. Over the four complete gridblocks in Figure 4, i.e., the coast from 36°55' N counterclockwise to 76°03' W, total net shoreline movement during 1852 to 1980 is very nearly null. The lack of shore retreat after 1916 seems particularly notable because mean sea level in this area has been rising at about the largest rate recorded on the U.S. Atlantic Coast (Hicks et al., 1983), approximately 0.75 feet from 1928 through 1980. Mean high water would be expected to have moved appreciably landward in a plan view, so recent overall shore stability on Cape Henry in the central area mentioned above implies sizable quantities of littoral sand are supplied to the area.

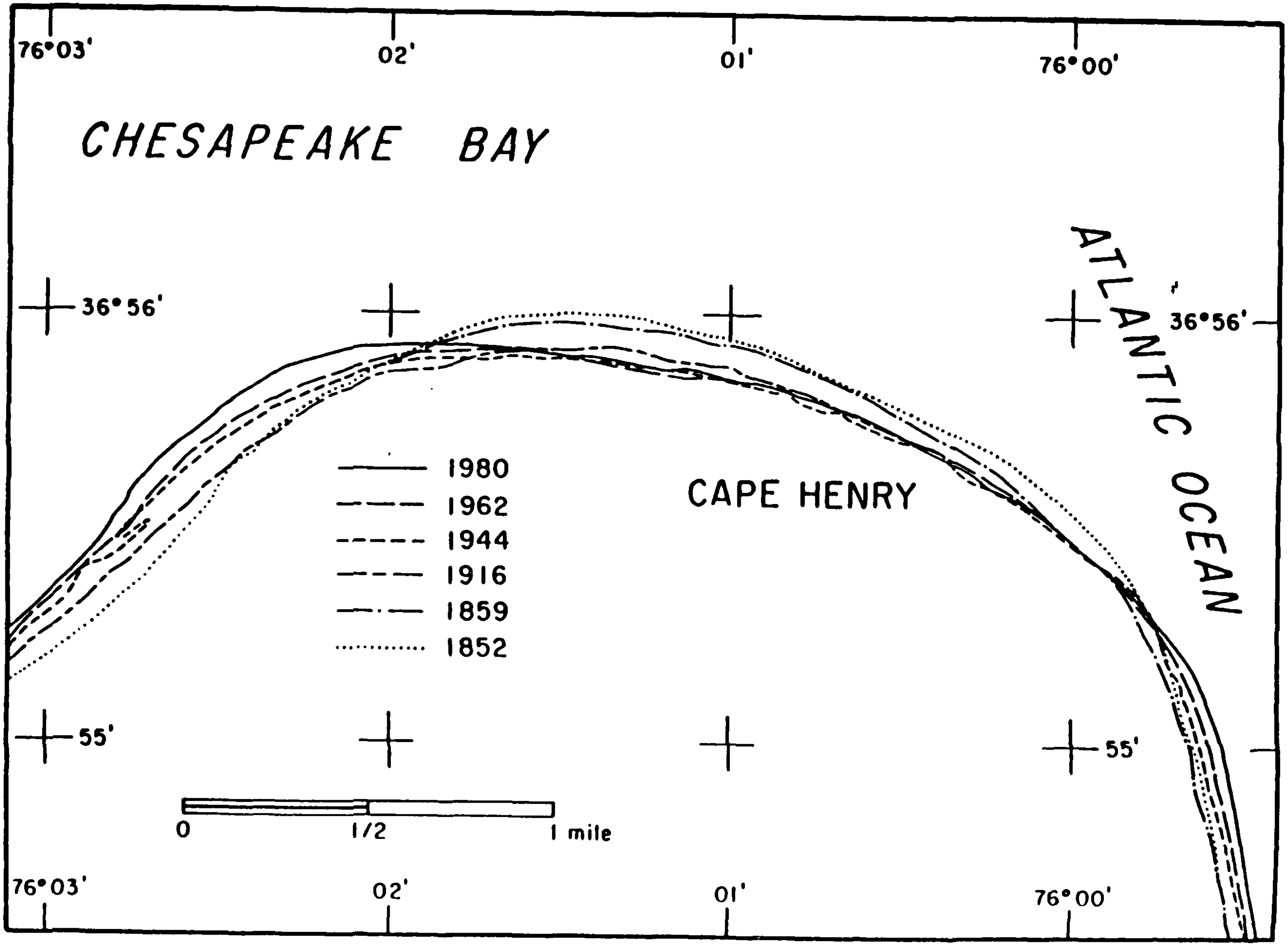


FIGURE 4. HISTORICAL SHORELINE MOVEMENTS AT CAPE HENRY FROM MAP NO. 43, EVERTS ET AL. (1983).

Table 1. Averaged shoreline movements between available surveys for Cape Henry, Virginia (Everts et al., 1983; page 59). Data have units of meters per year, with + indicating shoreline advance and - indicating retreat.

	Averaged rate over grid interval between surveys						Estimated Trend
Shoreline Longitude	1852-1859	1859-1916	1852-1916	1916-1944	1944-1962	1962-1980	1852-1980
76°02'xx"			+0.5	+3.3	+1.6	+3.7	+1.7
76°01'xx"	-6.8	-1.5		-0.7	-0.6	+1.1	-1.2
75°00'xx"			-0.7	-3.2	+0.5	+0.4	-1.1
75°59'xx"			-0.5	+1.1	+0.2	+2.0	+0.2

Goldsmith et al. (1977) reviewed evidence indicating that there is appreciable net longshore sand transport on the Atlantic coast north towards Cape Henry, with estimates on the order of 500,000 cubic yards per year viewed favorably. Based on variations in observed beach behavior and computed wave refraction, a nodal zone in longshore transport was inferred to be located adjacent to northern Back Bay, about 7 miles south of Rudee Inlet in the Virginia Atlantic coast; on the barrier islands south of there, net longshore transport is to the south, opposite the transport direction on the mainland beaches north of Back Bay. Northward longshore transport within the 7 miles between Rudee Inlet and Cape Henry is also consistent with the possible existence there of a "nontidal drift eddy" having clockwise motion.

Field investigations reported by Goldsmith et al. (1977) include repeated beach surveys during 1974 to 1976 on one line within Fort Story Military Reservation; see Figure 5 for location. That profile line, which has mainly Atlantic Ocean exposure, had exhibited a definite accretional trend since a previous study in 1969, then accreted throughout the Goldsmith study and even showed net beach volume gain from most storms, especially landward of the berm. The beach backshore is wide and flat, but the influence of heavy vehicular traffic and grading activities could not be assessed (according to Goldsmith et al. 1977).

Present Field Investigations. Field data collection during the summer of 1983 included profile surveying and sediment sampling on the 16 profile lines shown on Figure 5, and drogue studies of flood and ebb currents in two separate

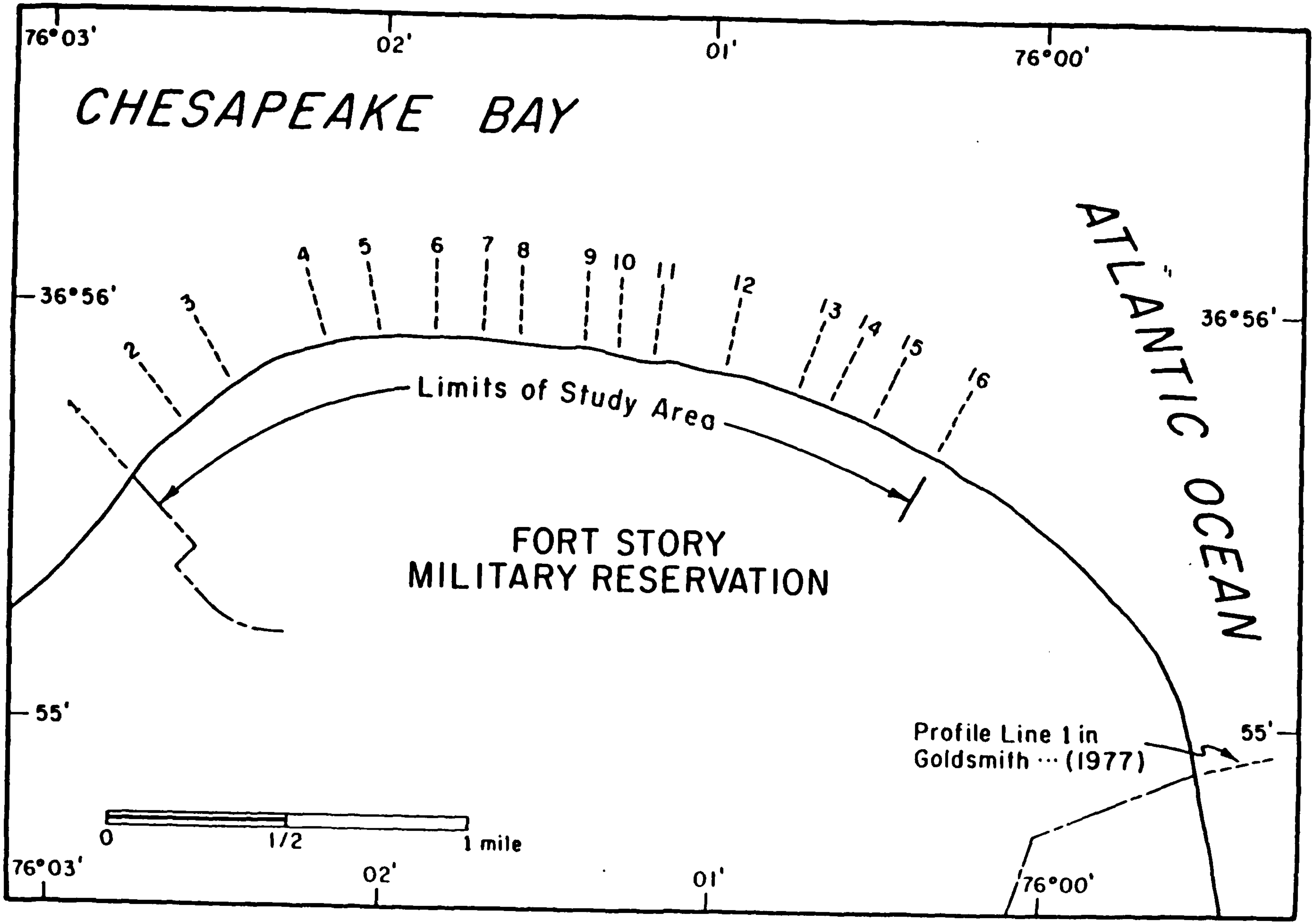


FIGURE 5. LOCATION OF PROFILE LINES AT FORT STORY, VIRGINIA, WITH 1980 SHORELINE FROM FIGURE 4.

areas near lines numbered 1 through 5 and 10 through 16. A complete log of field investigations and original data are available as a Supplement to the basic report.

Figure 6 displays hydrography determined from soundings extending at least 1000 feet seaward of MLW on each of the 16 profile lines. Depth contours are closely spaced near the western end of the study area but more widely spaced towards the eastern end, that is, nearshore slopes are less steep in the eastern end. Limited instances of relatively gentle nearshore bars are indicated by multiple intercepts of the -5 foot (MLW) contour along profile lines 3 and 5 (see Figure 6).

Other minor instances of landward tipping subaqueous slopes may be seen in Figure 7 A/B, which reproduces the entire profile determined at each beach transect, from offshore limit to beach dune. One purpose of these displays is to demonstrate the classification by profile shape introduced here. Profile lines 6 through 16 each exhibit an unusual, nearly horizontal terrace extending for about 300 feet near -6 or -7 feet MLW. Profiles 1 through 5 exhibit distinct resemblances in having appreciable extent and elevation of beach backshores, and in geometry near the shoreline and inshore regions. Profiles 8 through 16 form a regular sequence and show similar subaqueous geometry but various and limited backshore regions, with dunes relatively near the shoreline. Finally, profiles 6 and 7 comprise a transitional set, with beach width and dune location like those further east within the second set, but offshore geometry more nearly like that further west within the first set.

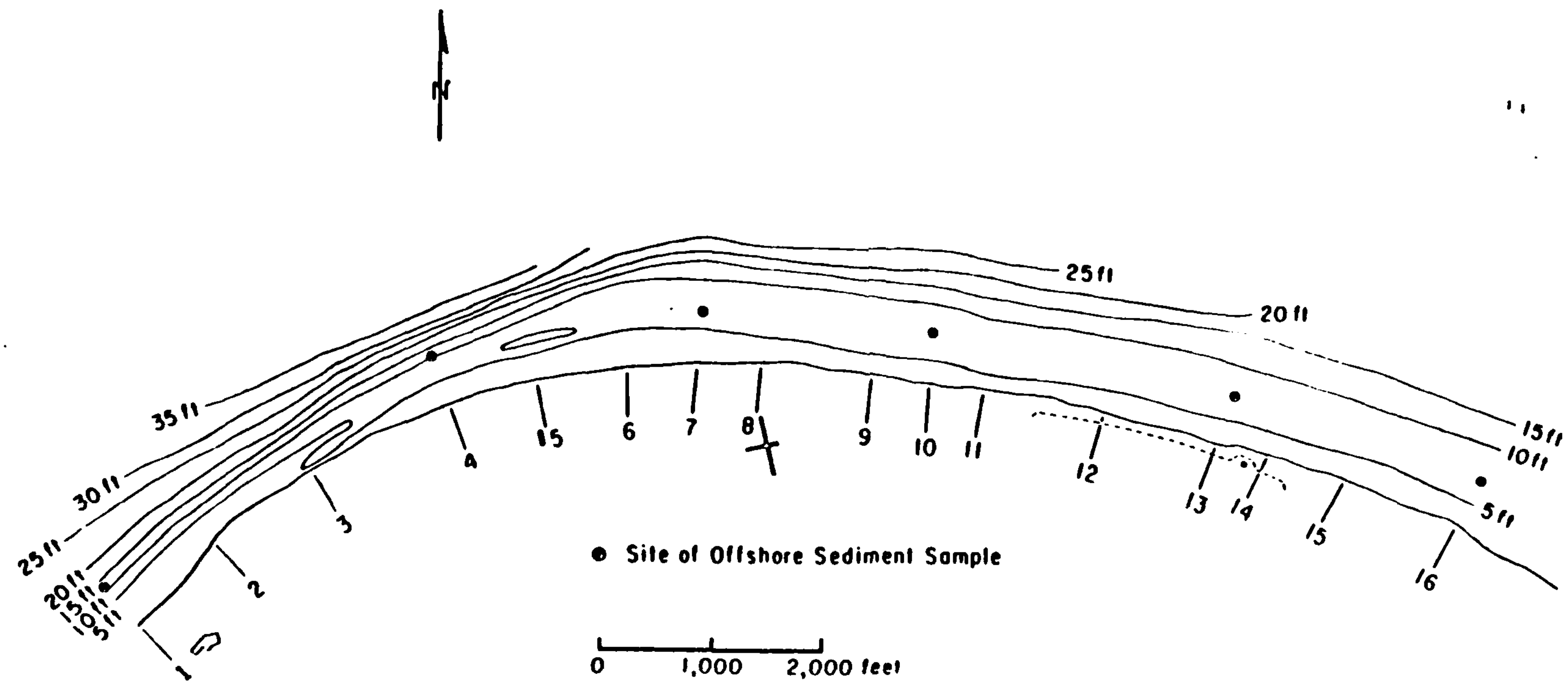


FIGURE 6. WATER DEPTH CONTOURS AND MLW SHORELINE FOR FORT STORY STUDY AREA, FROM SUMMER 1983 SURVEY

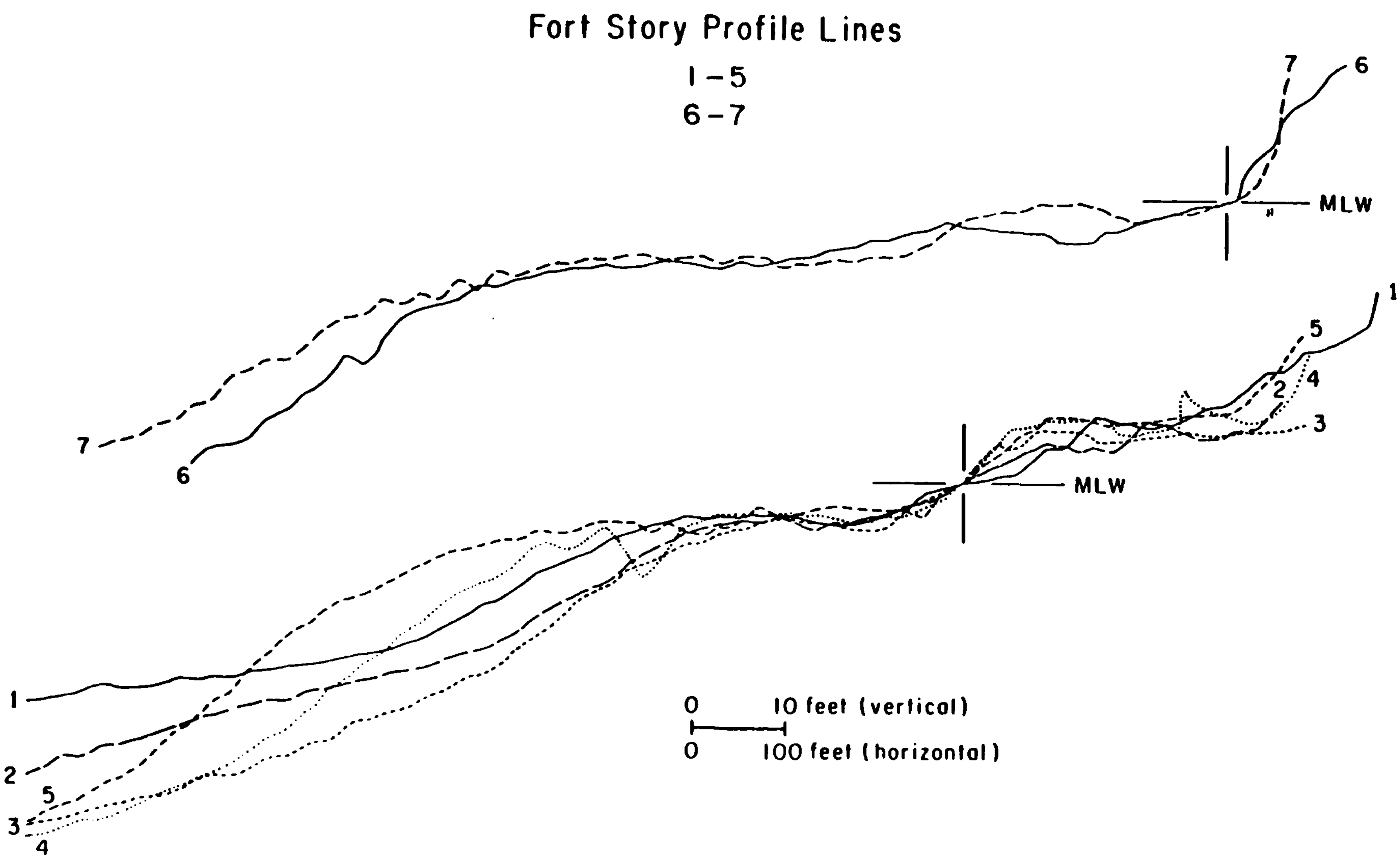


FIGURE 7A. SURVEY RESULTS FROM SUMMER 1983 FOR WESTERN PROFILE LINES, WITH 10x EXAGGERATION OF VERTICAL.

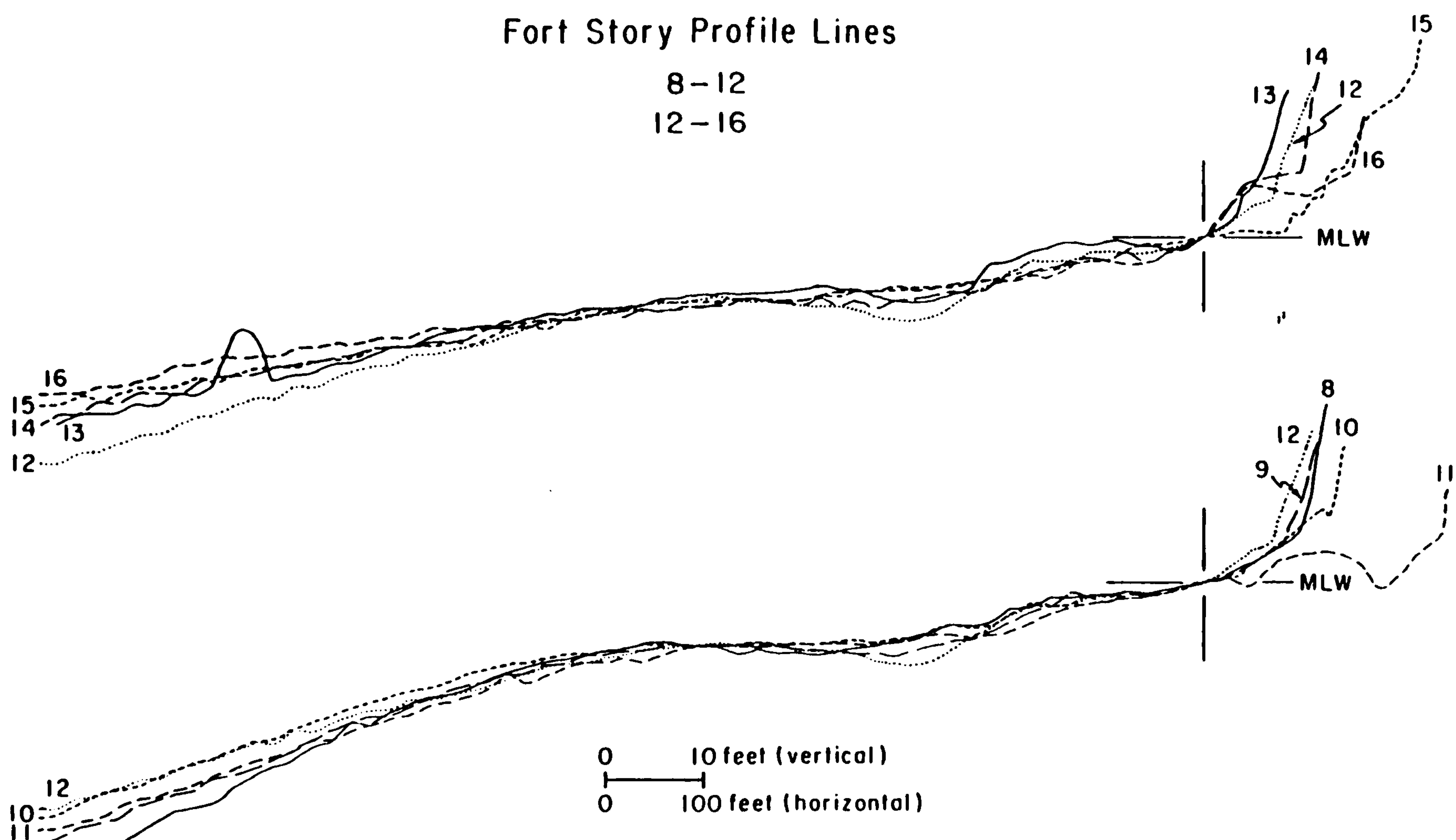


FIGURE 7B. SURVEY RESULTS FROM SUMMER 1983 FOR EASTERN PROFILE LINES, WITH 10x EXAGGERATION OF VERTICAL.

Sediment samples were collected along all 16 profiles, consistently at three locations: on the intermittently wetted foreshore, on the widest beach berm, and from the dune. Additional occasional sample sites were on the low-tide terrace at lines 1 and 15, and about 500 feet seaward of MLW intercept at the six locations indicated in Figure 6. Appendix B to this report provides plots showing variations with sampling site of the median and extreme sediment grain diameters (D_{50}, D_{16}, D_{84}) determined from sieve analyses of samples. All 53 samples at Fort Story are classified as sand and overall trends or tendencies include these: coarser sands occur to the west in the study area, and finer sands to the east; offshore/dune/low-tide terrace/berm/foreshore is the sequence of sample locations providing increasing coarse sands; and the coarser the median size, the wider the range of sizes in these sands. These statements each have exceptions, but provide an overview. For a greatly simplified quantitative summary, it may be noted that each sample has a least one of the size measures D_{16} and D_{84} within the range of grain diameters between 0.17 and 0.33 millimeters; that range might be viewed as representative of sands in the study area. There is much greater sand-size variation in the shore-normal direction on a single profile, than in the alongshore direction at nominally comparable sample sites on different profile lines.

The final class of new field data are results from drogue studies of local tidal flow, which are summarized by the current speeds presented in Table 2. In the eastern study area, ebb flow predominates over weak flood flow. In the western study area, surface currents are all significant in that their speeds are on the order of one foot per second which can move local sands. The ebb is slightly greater than the flood at peak flow in this western area. Observed

Table 2. Results from drogue studies of tidal currents within Fort Story study area. Data have units of feet per second.

Ebb Tide

	Observed Current Speeds:	
	Lines 1-5	Lines 9-16
Mean:	1.5	2.7
Median:	1.5	2.5
Range:	1.0 - 1.8	1.3 - 4.2

Approximate speed expected near Cape Henry*: 3.7

Flood Tide

	Observed Current Speeds:	
	Lines 1-5	Lines 9-16
Mean:	1.4	0.4
Median:	1.3	0.4
Range:	1.2 - 1.7	0.2 - 0.7

Approximate speed expected near Cape Henry*: 1.2

*Mean of maximums expected during times of drogue studies, for 1 mile north of Cape Henry Light; from pages 67 and 163 of "Tidal Current Tables 1983, Atlantic Coast of North America." (National Ocean Survey, 1982)

directions of all the faster currents were basically parallel to the local shoreline in the two areas monitored, but weak flood currents usually were oblique to shore in the eastern study area. Ludwick (1970) interpreted net flow patterns in the Chesapeake Bay entrance as evidence that the entire nearshore area bordering the Cape Henry promontory was strongly dominated by ebb flow, with a corresponding ebb-directed net transport of bottom sediment; however, the 1983 data indicate a more complicated situation exists.

In addition to the detailed field studies during June through August 1983, Fort Story beaches were informally inspected, photographed, and sampled on 23 May and 14 December 1983. Inspection of identical sites revealed seasonal effects in that the beaches clearly had accreted between the two visits, although surface sands were not visibly different.

COASTAL PROCESSES IN STUDY AREA

One essential consideration for the present work is the overall pattern of sediment transport near Cape Henry. Field investigations described above addressed present conditions rather than processes, and no definitive study of dynamics in the Cape Henry region was located during preliminary literature review. Thus, an overview of coastal processes in the study area must be developed from accessible information and rational estimation procedures.

Local Environment. Extensive information is available on the marine environment for the Chesapeake Bay entrance. Table 3 provides a summary of nearby sea measurements:

Table 3. Summary of basic marine environmental measurements for region near Fort Story.

A. **Sea Level Trend** (Hicks et al., 1983)

Hampton Rds Station: 36°56.8'N, 76°19.9'W
+4.3 mm/year (0.014 ft/year), 1928 through 1980
+3.6 mm/year (0.012 ft/year), 1940 through 1980

B. **Tidal Characteristics: 1983** (National Ocean Survey, 1982 a/b.)

Shore Sites	Mean Tide Level (feet MLW)	Mean Range (feet)	Spring Range (feet)
Hampton Roads 36°57'N, 76°20'W	1.2	2.5	2.9
Lynnhaven Inlet 36°54'N, 76°05'W	1.0	2.0	2.4
Cape Henry 36°56'N, 76°00'W	1.4	2.8	3.4
Virginia Beach 36°51'N, 75°58'W	1.7	3.4	4.1

Marine Sites	Flood (knots/degrees)		Ebb (knots/degrees)	
Lynnhaven Roads 36°55.1'N, 76°04.9'W	0.8	280	0.9	070
1 mile north of Cape Henry Light 36°56.4'N, 76°00.5'W	1.1	280	2.0	090
0.7 mile east of Cape Henry Light 36°55.7'N, 75°59.6'W	1.0	320	1.9	105
Thimble Shoal Channel 36°58.33'N, 76°06.67'W	1.4	310	1.3	095

C. **Wave Climate** (based on data in Thompson, 1977)

	Expected Wave Conditions:		
	Average	Median	Extreme
Thimble Shoal Channel 36°58'N, 76°07'W April 71 through Aug 74			
Height, ft:	1.62	1.35	7.6
Period, sec:	3.70	3.40	5.5
Virginia Beach 36°51'N, 75°58'W Dec 68 through Oct 69			
Height, ft:	2.38	2.03	9.8
Period, sec:	8.32	8.40	8.8

water levels, currents and wave characteristics. Sea level is rising relatively rapidly, as mentioned previously; tides are semiduirnal with a moderate range but notable current velocities; and wave heights in the vicinity can be fairly large for "extreme" conditions, to be expected 12 hours per year.

Cape Henry has appreciable exposure to the Atlantic Ocean and to a long reach in Chesapeake Bay, so that relatively long ocean swell and shorter, locally-generated waves both may be influential. Available data provide no information on wave directions, an important factor in coastal processes, but some assessment of dominant local wave directions can be based on prediction procedures using local wind information. Figure 8 summarizes 1981 data on winds at the Chesapeake Bay Bridge-Tunnel in the form of a wind rose: frequency of occurrence for three ranges of speeds and 16 separate directions. Highest winds were usually somewhat northerly, during winter, and notable summer winds were easterly or southerly and of moderate speed.

Besides this data on environmental forces, information on possibly associated characteristics of the sea bottom near the study area has been provided by Meisburger (1972). Figure 9 presents extracts from his conclusions on gross geomorphology and surface sediments for the southern part of the Chesapeake Bay entrance. Meisburger set a distinction at -33 feet MLW to divide deep entrance waters from the extensive and flat shoal areas (above -30 to -36 feet MLW elevations). All evidence indicated that surface sediments are appreciably active due to currents and waves at present only on the shoals and shoreface. An account of coastal processes near Cape Henry must be consistent with local indicators displayed in Figure 9.

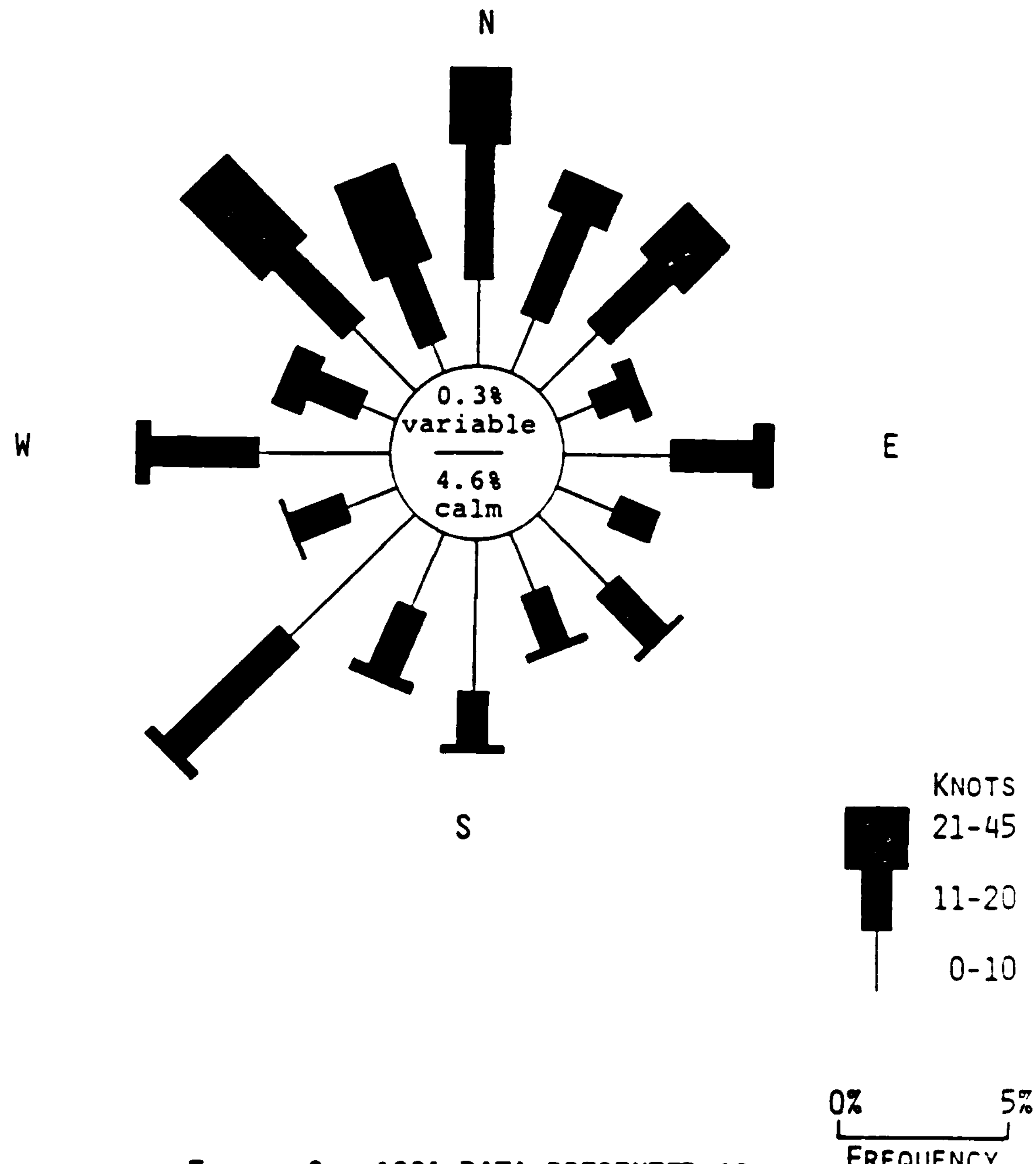
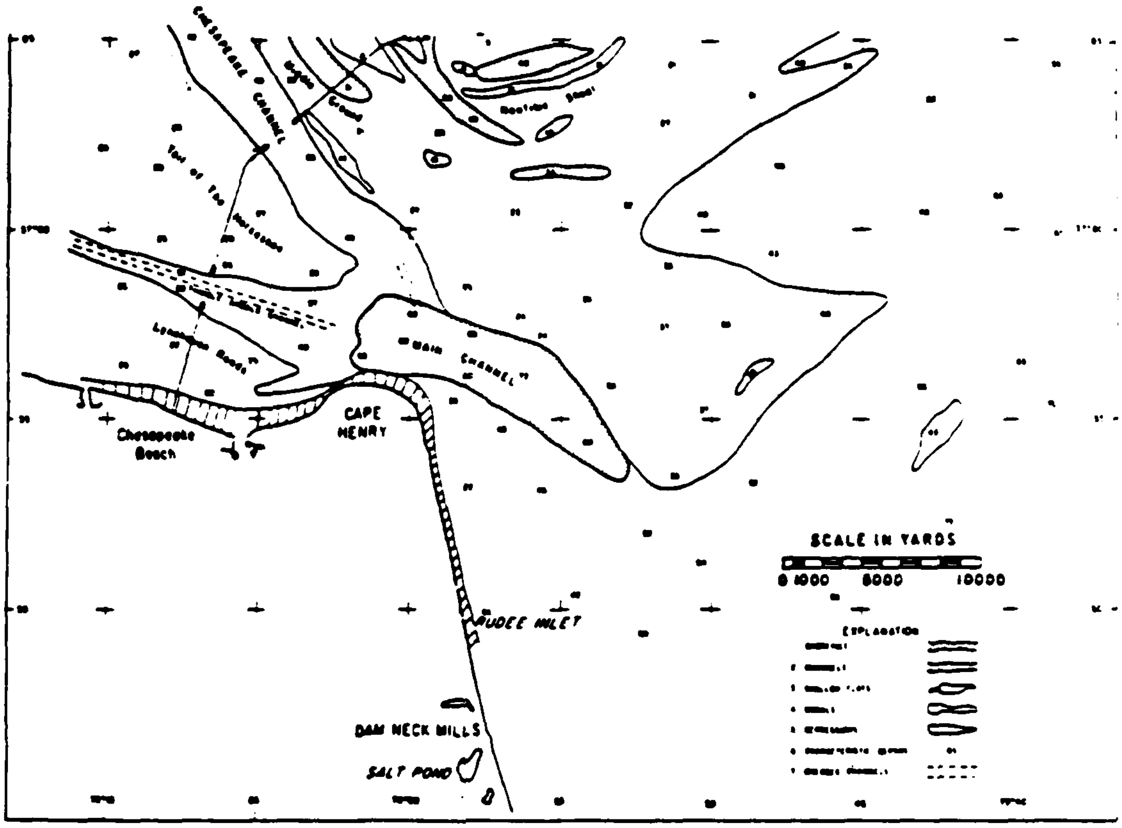


FIGURE 8. 1981 DATA PRESENTED AS ANNUAL WIND ROSE - CHESAPEAKE BAY BRIDGE-TUNNEL

A



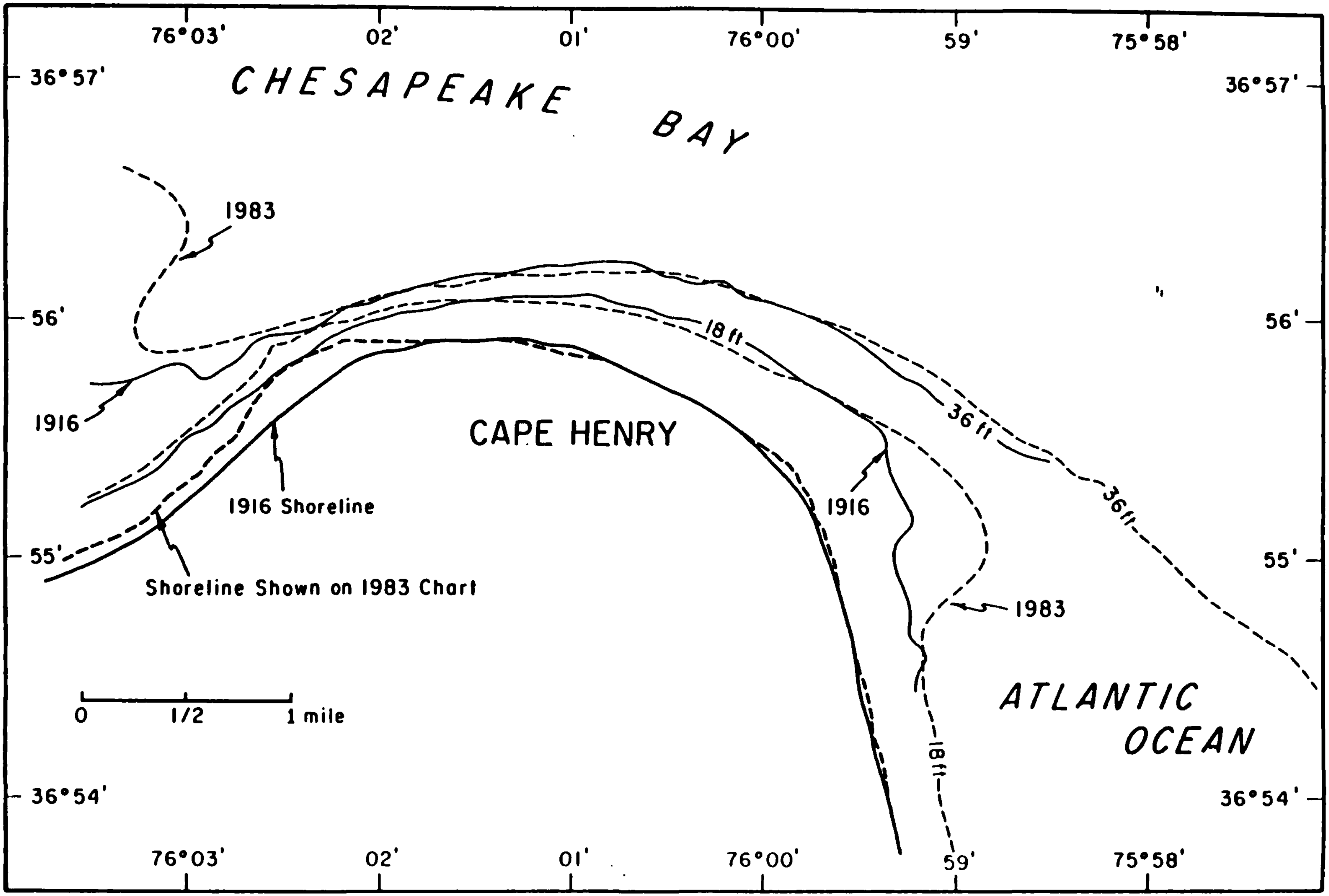
B

FIGURE 9. CONCLUSIONS PROVIED BY MEISBURGER (1972) ON:
A-GROSS GEOMORPHOLOGY; B- SURFACE SEDIMENTS NEAR THE CHESAPEAKE BAY ENTRANCE

Figure 9 patterns might be regarded as long-term effects of coastal processes, and shoreline movements in Figure 4 indicate some effects over shorter terms. Other significant evidence can be located: Figure 10 is a sketch comparing hydrographic contours at present near Cape Henry with those according to a 1916 survey (traced by H. Bruder from a chart in the NOAA Archives, Rockville, Maryland). One major change is the shape and location of the 18-foot depth contour east of Cape Henry at 36°55' N latitude; distance from shore to that contour more than doubled as a sizable seaward bulge has developed.

Computations. Appendix C documents procedures and results of investigations aimed at quantifying the exposure to Chesapeake Bay waves at the Fort Story study site. The basic question addressed was how representative of Bay waves at Cape Henry are measured waves at the Thimble Shoal Channel gage site (Table 3c)? Separation between these sites is only about 5 miles, but the irregular Bay shoreline and hydrography cause concern. Computations included geometrical analyses, and wave forecasts emphasizing NW, NNW, and N wind directions, because these provide 56% of all cases with winds exceeding 20 knots in the Figure 8 wind rose. Findings may be summarized briefly as follows.

For the wave gage site at Thimble Shoal channel, effective fetch for wave generation was determined to be 29.4 nautical miles, with the central fetch radial located at 356° and a representative water depth of 35 feet MLW within the fetch. Near profile line 6 at Fort Story, effective fetch to Chesapeake Bay was 28.5 nautical miles with central radial at 353° and representative depth of 37 feet MLW. With respect to the individual central radials, fetch at Fort Story is somewhat more appreciable westward, so that



Taken from NOAA Map Archives and Chart 12222 (June 1983)

Figure 10. NEARSHORE CHANGES AROUND CAPE HENRY, 1916 to 1983

350^{o} might be a better choice of central direction, whereas fetch at the wave gate site is just slightly more appreciable eastward. Each site has its major exposure into the predominant directions of strongest winds, somewhat west of north, while the slight differences in respective effective fetch and water depth have minor and counteracting effects on wave conditions forecast by standard methods.

Table 4 presents examples of Chesapeake Bay waves forecast for strong winds and basic site conditions stated above. Comparison with Table 3c confirms that these computed wave heights and periods correspond to measured storm conditions, i.e., larger than ordinary waves, at the Thimble Shoal Channel gage site. These results give confidence that available gage measurements can be adopted to describe the expected range of Chesapeake Bay waves within the Fort Story study area. This leaves the local character of waves from the Atlantic Ocean as a matter to be addressed.

Concerning that matter, net longshore transport is to the north between Rudee Inlet and Cape Henry, establishing that the predominant local direction of Atlantic Ocean waves is southeasterly and that longshore transport due to that wave source is basically counterclockwise around Cape Henry. Periods of local Atlantic Ocean waves are also clearly defined, being invariant in nearshore wave transformations, but Atlantic wave heights at the study site are difficult to determine, since refraction and frictional dissipation on longer propagation paths are expected to cause appreciable decreases relative to wave measurements at the Virginia Beach gage site (Table 3c).

Table 4. Wave forecasts for lower Chesapeake Bay with northerly winds. Basic situation with effective fetch = 30 nautical miles and water depth = 35 feet closely corresponds to either Fort Story study area or wave gage site at Thimble Shoal Channel.

Wind Speed knots	Wave Height feet	Wave Period seconds
25	4.4	4.5
30	5.2	4.8
35	5.9	5.2
40	6.5	5.5

The major use of wave data in this report is to estimate seaward limits to effective sand transport, and a reasonable approach is adopted to make use of available wave measurements. The seaward limits considered are those documented in Hallermeier (1981): a maximum water depth for surf effects, based on an extreme wave condition, d_s; and a maximum water depth for usual sand motion, d_m, based on the median wave condition and sand diameter. For measured Atlantic Ocean waves at Virginia Beach, d_s = 22.1 feet and d_m = 66.2 feet, whereas d_s = 13.3 feet and d_m = 17.8 feet for measured Chesapeake Bay waves using Thimble Shoal Channel gage data; with each set of wave measurements, D = 0.13 mm is taken for the fine gray sand common in both southern Chesapeake and Atlantic Ocean nearshore regions according to Meisburger (1972), and all depths are with respect to MLW. These limit depths were proposed to be valid only on straight, open coasts (Hallermeier, 1981); however, on a curved shore where exposure varies, such as Cape Henry, the basic concepts involved in these seaward limits remain pertinent and actual limit depths would be expected to vary smoothly with location.

With this in mind, moderate estimates of limit depths at the Fort Story study site having mixed wave exposure can be obtained using even blends of the individual wave climates summarized in Table 3c. Forming the mean between Chesapeake Bay and Atlantic Ocean results for median and extreme wave conditions, limit depths are found to be d_s = 16.7 feet and d_m = 38.7 feet at the region of interest. These values are to be rounded upwards to the nearest foot for engineering usage. Estimated seaward limits are expected to be representative but perhaps too small for the

Fort Story site, because only wave action is considered but the additional tidal currents must increase local sand agitation and actual limit depths.

One more computation provides both an example of limit-depth applications and some implications about Cape Henry processes. An estimate of shore erosion rate due to sea level change can be obtained using the "Bruun Rule" (Bruun, 1962, 1983), which states that horizontal shore retreat equals vertical sea level rise divided by limit depth for sediment exchanges between nearshore and offshore (d_m), and multiplied by horizontal distance between the shoreline and that water depth. For Fort Story geometry, recorded sea level trend in Table 3a thus entails shore retreat of about 0.2 meters per year over the past half century. (Simple submergence with a representative 1 on 15 foreshore slope would yield only a shore retreat rate of about 0.06 meters per year.)

As with the limit depths previously introduced, the Bruun Rule treats coastal processes only in a profile view and thus is not exactly appropriate on curved shorelines. Nevertheless, the computed retreat rate should be a meaningful first-order estimate of net long-term effects ascribable to onshore-offshore sediment transport, for which the Bruun Rule is a unique and tested computation procedure. Among the shoreline movement rates in Table 1, median magnitude is 1.1 meters per year and there are both shore advances and retreats, so that the value given by the Bruun Rule clearly supports this notion: longshore rather than onshore-offshore sand transport is the dominant component in coastal changes near Cape Henry. Note also that sand is available for exchanges with the beach only to a limited extent offshore of the Fort Story study area (Figure 9).

Preliminary Overview. An important factor in summarizing coastal processes near Cape Henry is the likely direction of net longshore sand transport, due to Chesapeake Bay waves considered separately. Table 5 presents measured variations in shoreline orientation within the Fort Story study area, and these values are to be compared with the primary Bay exposure of these sites: fetches longer than 50 nautical miles lie approximately between compass headings of 000° (north) counterclock wise to 345° (west of north). With respect to that direction band, the Fort Story shoreline can be divided into three segments of differing alignment: lines 9 through 16, where transport by Bay waves is expected to be usually towards the Atlantic Ocean; lines 1 through 4, where the usual transport by Bay waves is expected to be in the opposite direction; and lines 5 through 8, hypothesized to be a nodal zone of divergence for longshore sand transport due to Chesapeake Bay waves only.

Another distinction to be made along the Fort Story shore concerns the relative significance of ebb and flood flow velocities, discussed in conjunction with Table 2. Flood currents dominate in the eastern study area but peak ebb and flood currents are both moderately strong and fairly balanced in the western study area.

A third meaningful distinction along the shore within the study area is the varying blend of wave energy incident from Chesapeake Bay or Atlantic Ocean. Available data and appropriate techniques for a preliminary study do not permit an informed judgement on this matter at present. The alternative adopted here is to form an evenly weighted mixture of Bay and Ocean wave characteritics, then estimate the limit depths d_s and d_m presumed applicable throughout the study

Table 5. Approximate shoreline geometry at Fort Story profile lines. Data are compass directions measured from 1983 survey sheet.

Line Number	Direction of Shore Normal (degrees)
1	316
2	306
3	329
4	334
5	348
6	355
7	358
8	000
9	008
10	007
11	009
12	016
13	018
14	017
15	021
16	026

area. The first approximation to demarcating coastal processes by means of these two depths seems validated in sea-bottom features near Cape Henry.

The 36-foot depth contour, comparable with d_m estimated at 39 feet, forms a smooth arc north of Cape Henry, but in Chesapeake Bay, this contour ceases to follow the shoreline (Figure 1). Also, this contour nearly overlays the Figure 9 break between sand-sized and finer bottom material north of Cape Henry but not further westward. These facts are consistent with active shaping of a sandy shoreface by usual flows out to d_m offshore of the study area, but only to lesser water depths further within the Bay (compatible with reduced limit depth to moderate bed activity there).

Concerning the other type of limit depth, attention is concentrated north and east of Cape Henry, where the transition to full Atlantic Ocean wave climate must occur. The 18-foot depth contour, comparable with d_s estimated at 17 feet, does seem to constitute a meaningful indicator (Figure 10) of coastal processes in terms of the seaward limit to surf effects, which include appreciable longshore sand transport. The marked eastern advance of that contour between 1916 and 1982 indicates appreciable deposition over an area of about one million square yards; at present, no comparable bulge occurs in the 12- or 30-foot depth contours. On the present 18-foot depth contour, the shapes of its northeastern and southeastern faces suggests that deposited sand is from the north rather than the south. However, the actual (ultimate) sediment source must be the large net longshore transport towards the north on the Atlantic shore.

The resolution of these somewhat contrary indications is permitted by recognizing that longshore transportation capacity of wave action may be expected to diminish from the Atlantic to the northern section of Cape Henry, due to lesser exposure to the Atlantic Ocean and opposed Bay wave directions. Thus, there must be some deposition of littoral drift proceeding counterclockwise around Cape Henry. Deposited sand, especially that in relatively deeper littoral-zone waters approaching d_s, is subject to transport by locally predominant ebb-tidal currents approximately paralleling the shoreline. The boundary of shore-attached ebb flow predominance outside the bay is (Ludwick, 1970) just about at the southeastern face of the contour bulge under discussion, so that the apparent limit to the transport mechanism agrees with the limit to ultimate sand deposition. Restriction of deposits to that 18-foot water depth can be associated with two factors most appreciable shoreward of that contour: coastal sands being supplied from the south and wave-induced bed agitation assisting sand mobilization.

To summarize this overview of coastal processes, Figure 11 provides a sketch indicating tentative inferences about principal sand transports near Cape Henry. Bay waves and ebb tides are marine forces tending to generate eastward longshore transport near lines 9 through 16 within the study area, but field observations demonstrate that the transport balance does not tip eastward there: shore deposition and erosion patterns confirm net east-to-west sand transport near the revetment projection between lines 13 and 14, and near line 11 where twin gun turrets are in a slight shore indentation. Net longshore transport must be basically westward (or counterclockwise) along the entire Cape Henry shore to supply sand accounting for the uniform historical accretion west of 76°02' W longitude (Figure 4).

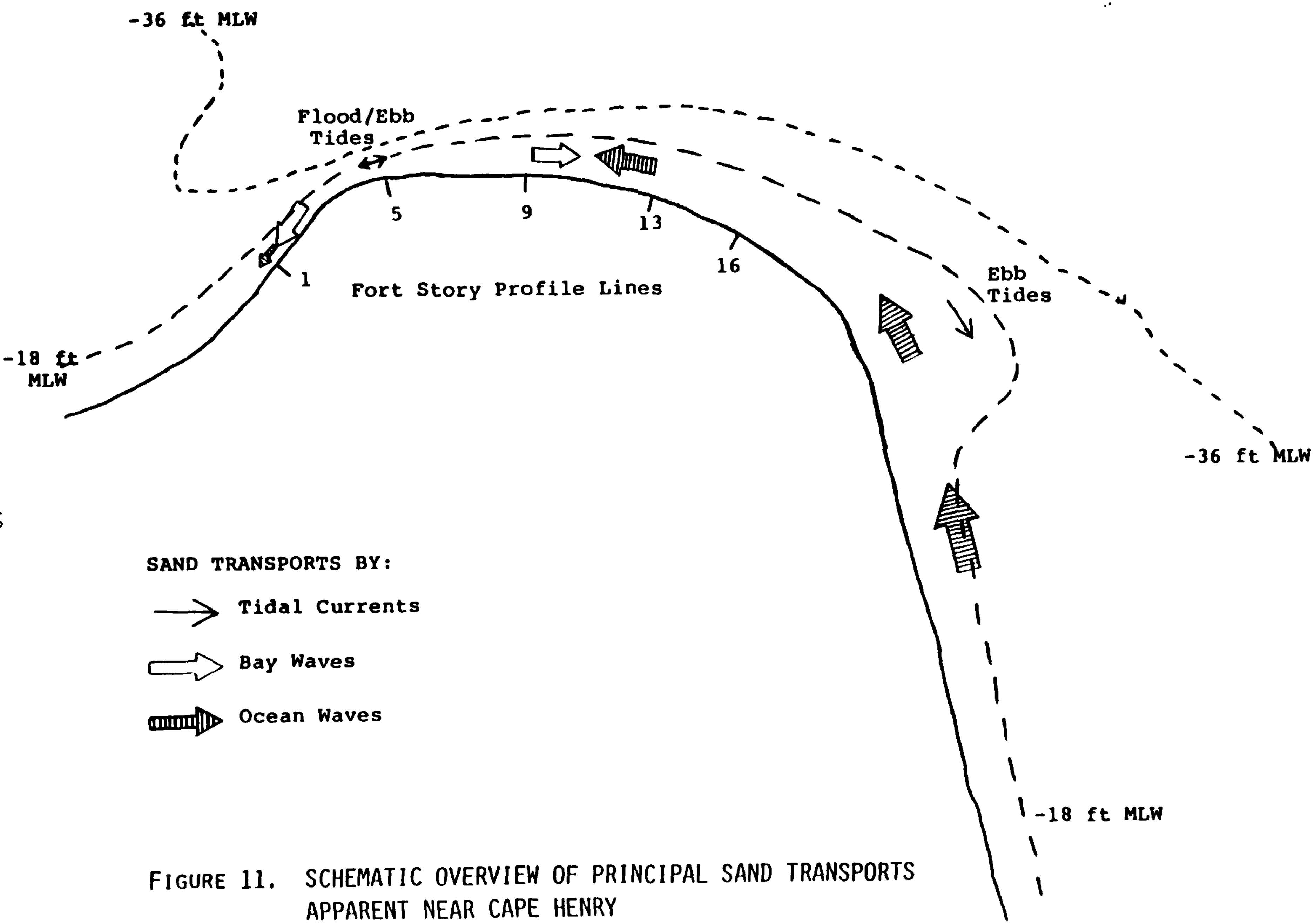


FIGURE 11. SCHEMATIC OVERVIEW OF PRINCIPAL SAND TRANSPORTS APPARENT NEAR CAPE HENRY

The sand recirculation effect building the shoal east of Cape Henry seems to be of major importance. Although detailed history of nearshore changes has not been determined, great quantities of sand clearly have been removed from the littoral supply around Cape Henry, and shoal growth might favor further growth by providing increased shelter from waves and deposition of Atlantic littoral drift.

BEACH FILL AT FORT STORY

The culmination to preceding considerations is design of a beach fill suitable for the study area, and the following paragraphs describe the process and results of a preliminary design based on available data. Size characteristics of native and borrow sands are a crucial element in fill projects, and the first topic here. Then other site characteristics are utilized in developing the section for the beach fill.

Sand Characteristics. Fort Story beach sands are to be described by a composite grain-size distribution, but the best procedure for computing that composite is uncertain. Hobson (1977) describes four components of variability in sediment texture, and available Fort Story samples seem adequate only in having defined alongshore sediment variations; added samples are needed to disclose seasonal, shore-normal, and subsurface components of sediment variability. The limitations of the initial sediment sampling plan imply native sands cannot be exactly typified, but meaningful approximations towards fully adequate composites can be presented.

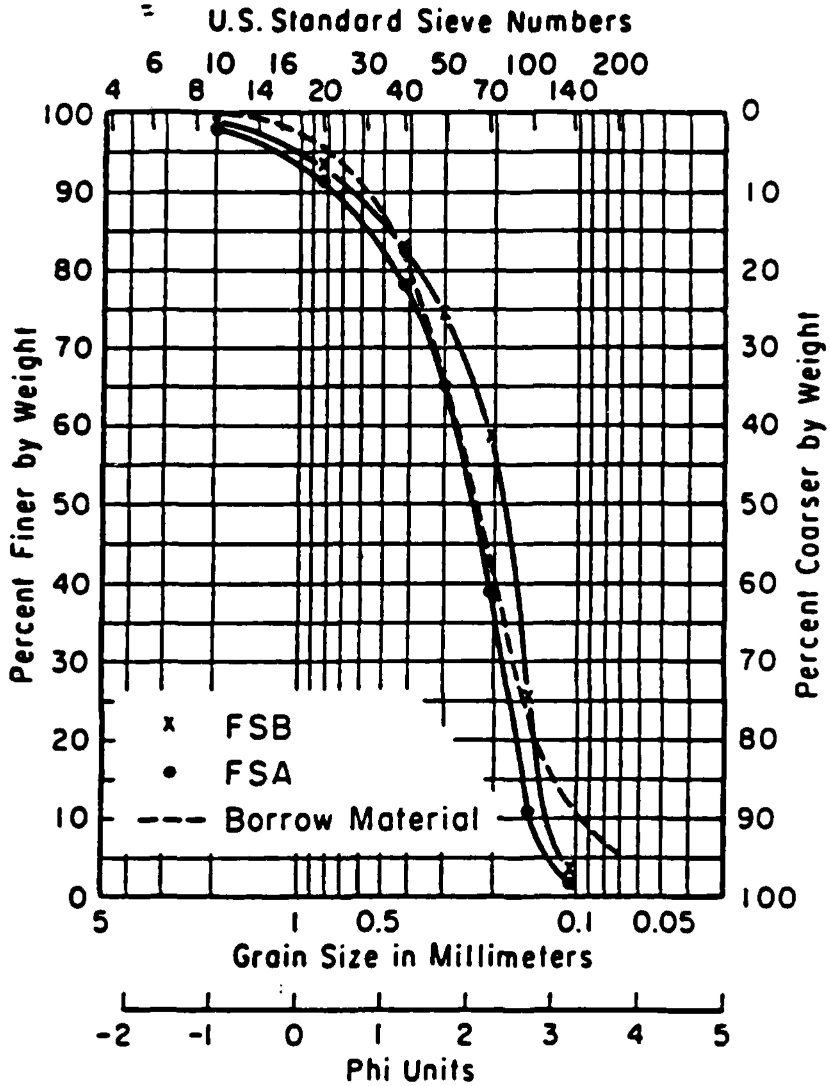


FIGURE 12. TWO COMPOSITE GRAIN-SIZE DISTRIBUTIONS (FSA, FSB) FOR FORT STORY BEACHES TO BE FILLED

Two native composites, FSA and FSB, were formed from available sediment analyses and are displayed in Figure 12. Each uses sediments sampled from the eroded Fort Story beaches - profile lines 9 through 16; dune samples are excluded because those sites are beyond the usual wave-dominated littoral transport system. FSA was computed by assigning equal weight to each of 20 samples from the region described. FSB was constructed to provide another description, judged more aptly balanced, for active littoral sands; here the three available offshore samples evenly provide half the composite, and berm and foreshore samples on those profile lines evenly provide the remainder. Figure 12 shows that these different computations provide fairly similar size distributions, and that the two native composites largely bracket the (Figure 3) composite describing borrow material from eastern Thimble Shoal Channel.

Table 6 summarizes computations relating to the compatibility of borrow sand as fill on the native beaches. Mean M and sorting S are obtained using D_{16} and D_{84} values from linear interpolation on phi-probability graphs, then M and S determine fill factors R by published design curves (Hobson, 1977; USA C.E.R.C., "Shore Protection Manual"). All computed individual fill factors are close to unity, indicating quantitatively that the native and borrow sands are closely matched for beach-fill purposes. The designated borrow sand may be described as about ideal beach fill, using the preferred FSB native composite; and as quite durable but not ideal beach fill, according to the FSA composite. These quantitative results from standard procedures actually seem contrary to visual evidence in Figure 12: FSA rather than FSB more nearly overlays the borrow material distributed

Table 6. Basic results in beach-fill computations, for borrow from deepening of eastern Thimble Shoal Channel applied to eroded shore on eastern half of Fort Story study area.

a. Descriptions of Sediments (phi units)

Parameter	Borrow Material Composite	Native Beach Composites: FSA	Native Beach Composites: FSB
D_{16}	1.09	0.89	1.17
D_{50}	2.10	2.05	2.38
D_{84}	3.01	2.64	2.91
$M = (D_{84}+D_{16})/2$	2.05	1.765	2.04
$S = (D_{84}-D_{16})/2$	0.96	0.875	0.87

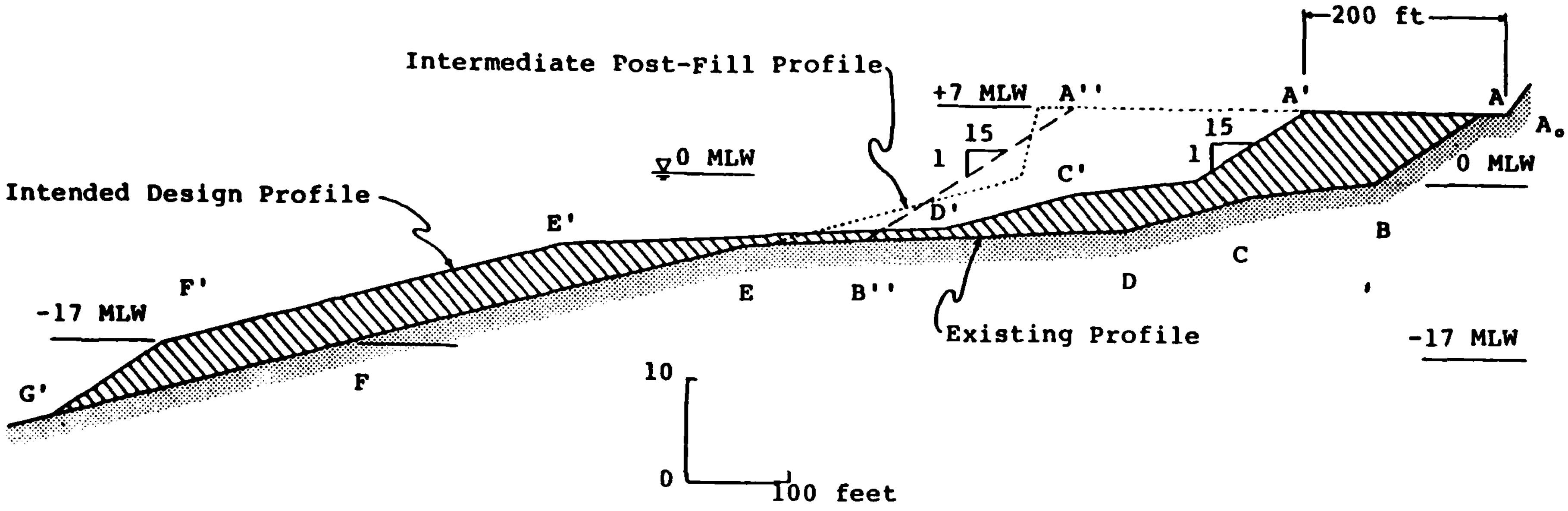
b. Suitability Measures for Borrow Material

Native Composite Employed	Adjusted SPM Fill Factor, R_A	Renourishment Factor (SPM), R_J	Dean (1974) Fill Factor, R_D
FSA	1.35	1.25	1.30
FSB	1.06	0.90	1.01

throughout its central 50% (but fill factors only take D_{16} and D_{84} into account). Considering either evidence, the gist is that borrow and native sands are closely matched.

Preliminary Design for Fill Section. Section 5.33 in "Shore Protection Manual" lists planning requirements for fill placement on eroded beaches, and Vallianos (1974) provides an example of the planning processes for one particular beach fill. On the Fort Story shore to be filled, there are limitations in available data that preclude an exact project design at present. These limitations include: composite descriptions of native and borrow sands are tentative; the deficiency in sand supplied as Atlantic littoral drift is not known quantitatively; and knowledge of longshore variability on eroded beaches is incomplete. This last point includes the facts that widely separated profiles cannot record localized shore geometries, e.g., the slight cove around the gun turrets near line 11, and that a single estimated d_s is an inadequate description for a shore where limit depth must vary due to wave exposure.

Incomplete site information does not prevent preliminary design of a typical beach-fill section for Fort Story, and this will illustrate basic magnitudes and results pertinent in final planning and design. Appendix D documents full details of applying guidance cited above to fill design for Fort Story beaches and develops the fill section summarized in Figure 13. This view includes the typical nearshore profile for the reach to be filled, along with the duplicate profile displaced seaward to yield the design berm width of 200 feet as the intention of the beach fill. Other design choices tailored to this locality are the berm



A_o-A Existing Berm
A_o-A' Design Berm Width
A_o-A-B-C-D-E-G' Existing Profile
A_o-A''-B'' Immediate (Hypothetical) Profile
A-A'-B'-C'-D'-E'-F'-G' Intended Design Profile

Segment	Length	Slope
AB	105 ft	0.0667
BC	120	0.0125
CD	125	0.0280
DE	380	0.0053
EF	385	0.0260

Intended Design Profile

Berm elevation	+7 ft MLW
Berm width	200 ft
Foreshore Slope	1 on 15

Segments of Intended Design Profile down to point F' have same lengths and slopes as corresponding segments of Existing Profile

FIGURE 13. PRELIMINARY DESIGN FOR BEACH FILL AT FORT STORY, TYPICAL GEOMETRY OF EXISTING, CONSTRUCTION, AND EVENTUAL PROFILES.

elevation set at +7 MLW and the foreshore slope of 1 on 15, both values based on available descriptions of stable beaches on the Fort Story shoreline.

An appropriate longshore extent of beach fill would appear to be from line 16 westward to midway between lines 8 and 9, about 2,000 yards of shore. This choice should assist a long residence time of the fill because it takes advantage of exposure to Chesapeake Bay providing some eastward longshore transport, while avoiding appreciable nearshore flood-tidal currents expected to increase net longshore transport rates further westward. The predominant longshore transport direction is westward throughout the study area, so that the vicinity of line 16 must be considered as a stockpile location and littoral drift will supply fill material to the marginally eroded beaches west of line 9.

Required volume of fill sand equals the shaded area indicated on Figure 13 multiplied by the longshore fill extent; for the stated geometry, this requirement is approximately one million cubic yards. Filling shore indentations is advisable to provide a smooth contour to the advanced shoreline, but existing irregularities have not been surveyed so that additional volume beyond that needed from typical-section consideration is not known. The basic strategy in beach-fill placement is to level material on top to +7 feet MLW extending any existing berm, and typical berm width at that time is about 425 feet, which should provide leeway to smooth shoreline irregularities. Redistribution of placed material will commence immediately under wave action on the exposed seaward face.

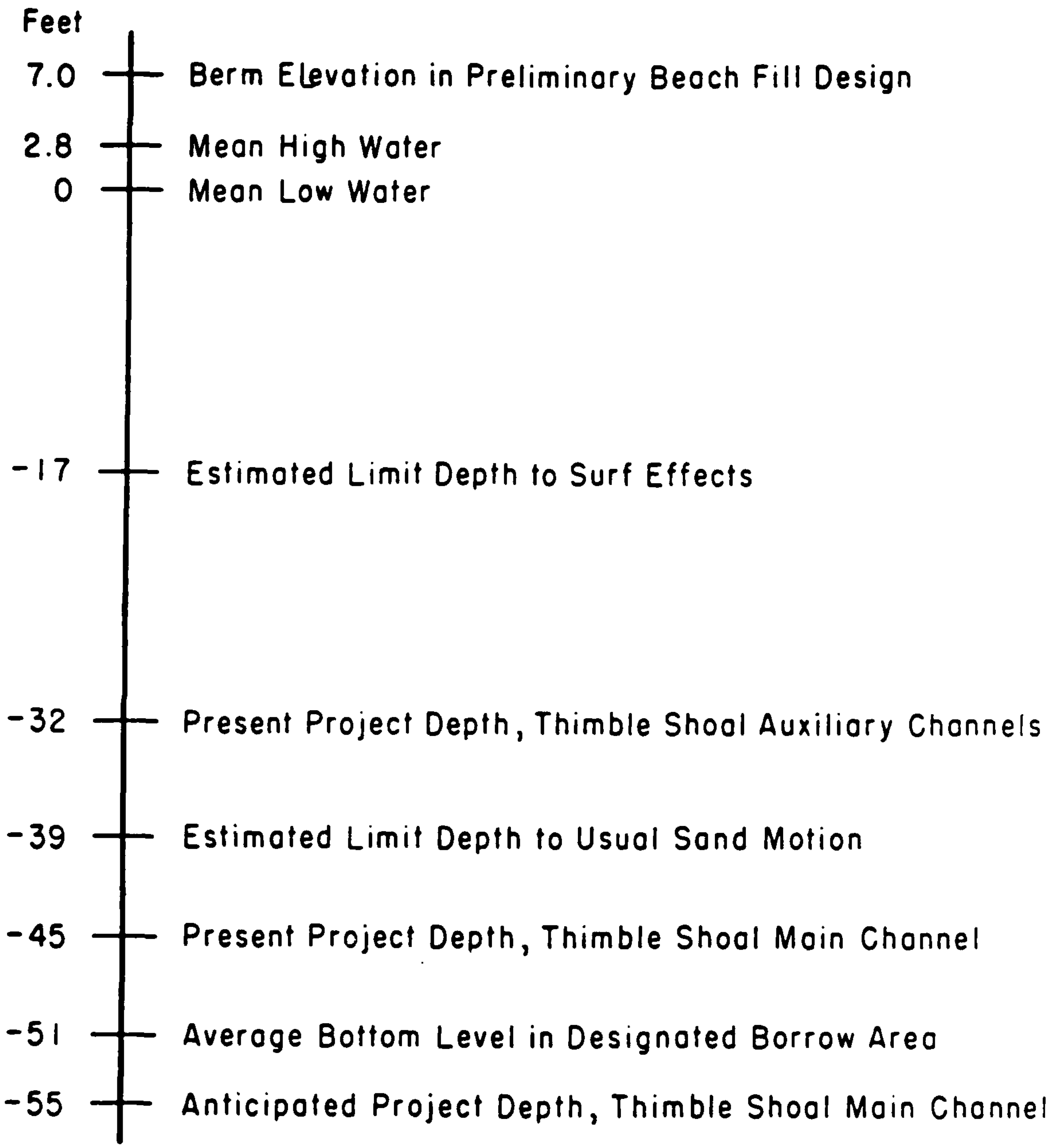


Figure 14. IMPORTANT ELEVATIONS FOR BEACH FILL PROJECT AT FORT STORY, VIRGINIA

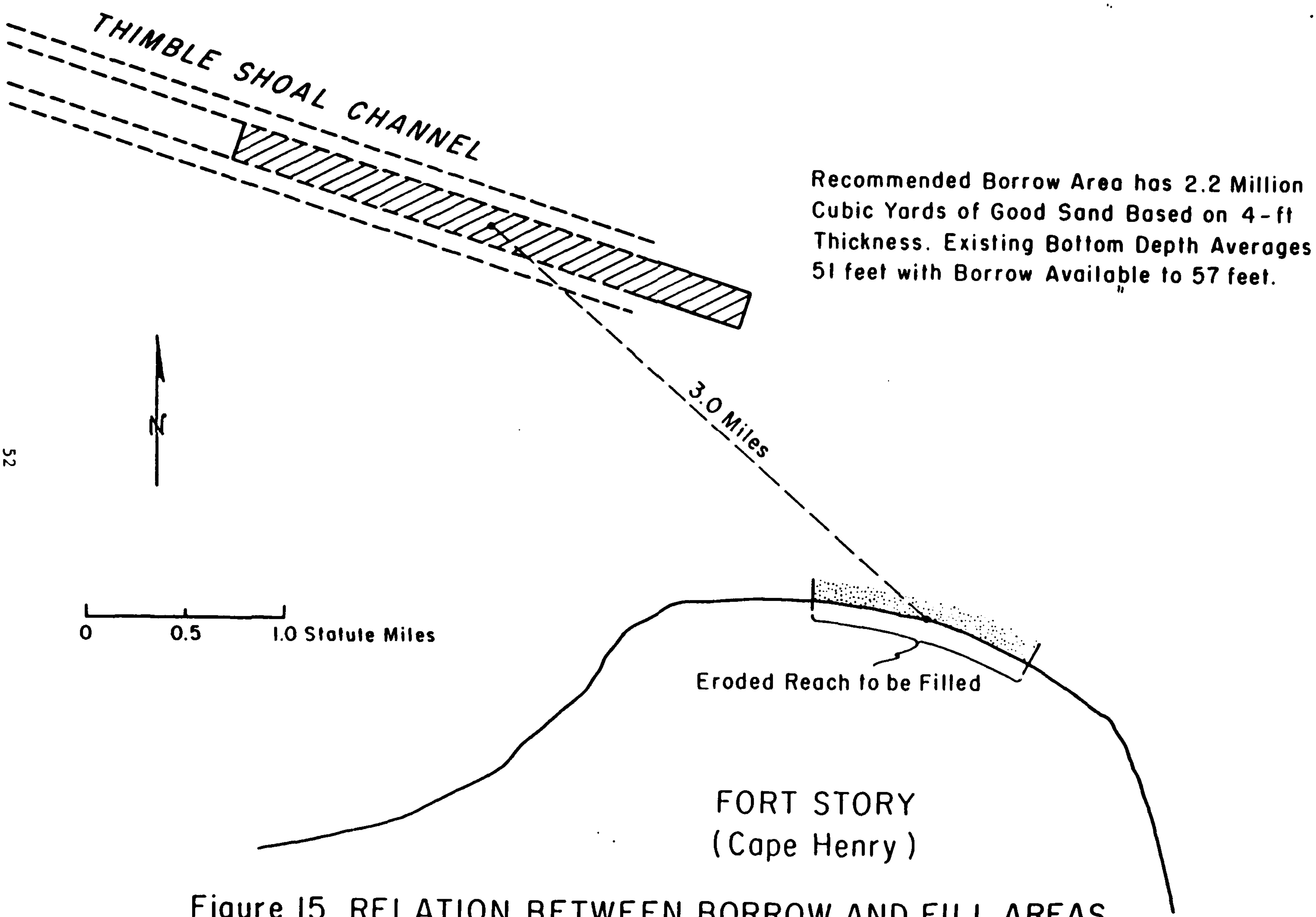


Figure 15. RELATION BETWEEN BORROW AND FILL AREAS

Figures 14 and 15 summarize other geometry involved in this analysis of potential beach fill at Fort Story. Figure 14 displays important vertical elevations, and Figure 15 shows the horizontal relation between borrow and fill sites.

SAND STOCKPILING

It is obvious that considerable, well qualified material is available from the channel for beach fill. It may well exceed the amount required for construction of the above profile. An expanded fill section could be considered however it would extend beyond the limits of new data acquired for this report. One potential result from constructing a larger section could be diminished durability of the additional material.

Stockpiling of the excess sand at Ft. Story has been sucessful in the past (Corps of Engineers, 1976) and appears feasible now. Stockpiling of dredged material can have as many complicating facts as beach or open-water disposal. Since Fort Story has single owner occupancy, then political and social problems are lessened since the owner can consolidate his desires as to where and how much. A good recommendation comes from this study with respect to the best location of a stockpile. The predominant longshore transport direction is west to east throughout the study area. Therefore, sand stockpiled near the eastern end could readily be introduced into the natural drift patters to supply the beaches around the cape. Figure 16 shows thus Sites, A, B & C which were viewed to have potential for sand stockpiling. The proximity of these sites to the shore would enable periodic spreading of the material along the foreshore. Should subsequent engineering work determine that beach fill is feasible east and south of the current study area, this sand could be used to accomplish this. Also, Site B is very close to the installation gate leading to Virginia Beach should the Army

east to west

decide to sell the commercially valuable resource to the Erosion Commission. It is noted that Site C is on U.S. Navy property so it is given its own distinction.

Another more inland site has been suggested nearer to the western gate. Site D shown on Figure 17 is situated in a shallow depression near the LACV-30 Maintenance Facility currently under construction. Likewise shown on Figure 17 is Site E near the beach. Both of these sites should be considered in view of their potential for noise abatement. Large, high, gently stopped stockpiles would serve as buffers. to sound by absorbing soung transmissions while reflecting residual noise skyward.

Topographic data is insufficant to allow a good quantative analysis of site capacities. Table 7 however presents some rough site characteristics sufficant for the intent of this study.

Table 7. General Characteristics of Five Potential Sand Stockpile Sites.

Site	Acreage	Average Elev. (ft)	Fill Elev (ft)	Capacity (D.C.Y.)
A	21	15	30	500,000
B	25	12	30	685,000
C	12	12	30	330,000
D	22	10	30	700,000
E	7	15	40	200,000
			TOTAL COMBINED CAPACITY	2,415,000

Adoption of the suggested sites is primarily the responsibility of the Army. The environmental setting of each site differs somwhat and each site, unless ruled out by the Post should be investigated in more detail.

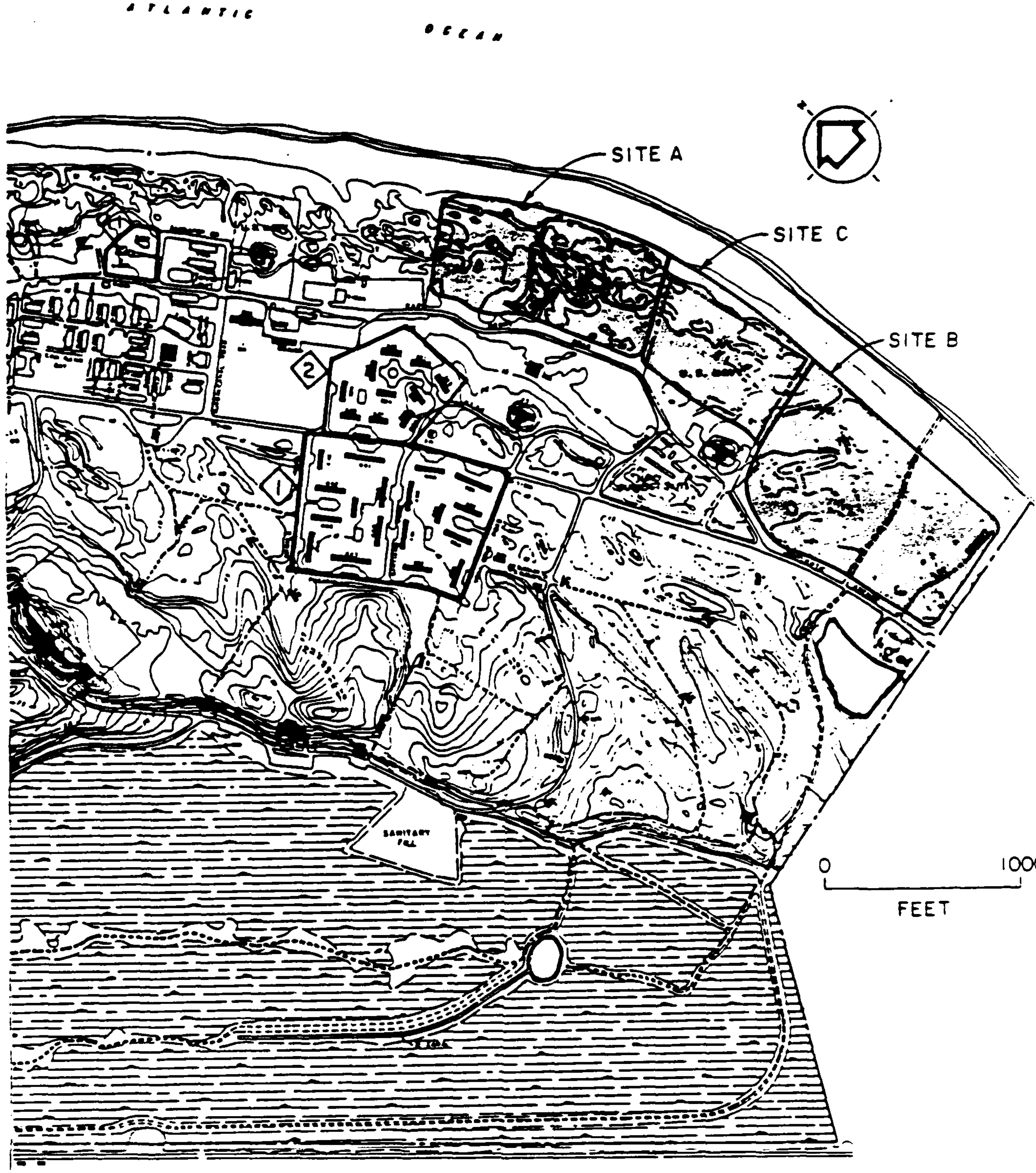


FIGURE 16. STOCKPILE SITES A, B & C

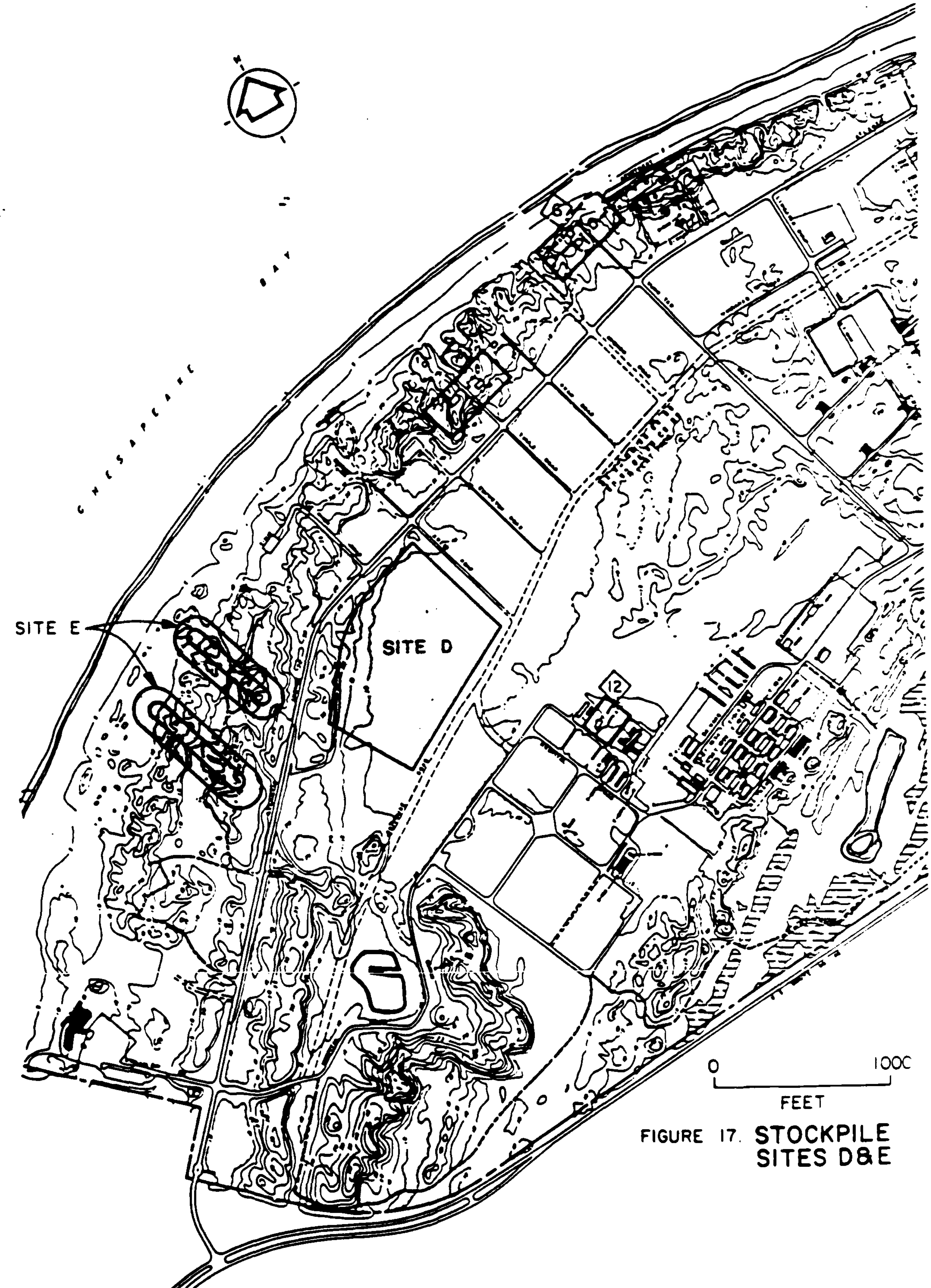


FIGURE 17. STOCKPILE SITES D&E

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The present investigation substantiates that sand from the designated borrow area in Thimble Shoal Channel is appropriate for filling eroded Fort Story beaches. New field data permitting this determination are: 42 cores taken near Thimble Shoal Channel (Appendix A); a survey of 16 profile lines at Fort Story (Figures 6 and 7); 44 measurements of nearshore tidal currents by drogue (Table 2); and sieve analyses of 53 sediment samples from study area site (Appendix B), with 6 in appreciable water depths. Further pertinent information from other sources includes wind and sea data (Figure 8, Table 3); recorded coastal effects (Figures 4, 9 and 10, Table 1); and estimated waves, limit depths, and transports (Figure 11, Tables 4 and 5, Appendix C).

Six questions were posed in the foregoing discussion on advance engineering, namely:

Is there available material proximate to nearby shores?
Is this material suitable for beach or stockpile fill?
Is the material compatable with natural shore deposits?
What slope should fill take?
Will it be durable?
Is stockpiling feasible.

The answer to the first question was shown to be somewhat dependent on the authorized project depth of the channel and parameters outlined by Whitehurst in his report. These parameters can be quantified based on Hallermier's foregoing analysis of tides and winds in lower Chesapeake Bay.

Whitehurst reported that in ~~Ocean Channels~~ exposed channels with wave affects, the following parameters should be taken into account to design the dredging depth:

Tide

Pitch, roll, or heave of design vessel

Draft of design vessel

Squat of design vessel

Safety clearence for design vessel

Advance maintenance dredging

Dredging tolerance

From Table 3 (this report) it can be seen that the Spring Range of Tide at Cape Henry exceeds that at Hampton Roads by 0.5 feet. Also Table 4 presents wave forecast data for northerly winds in lower Chesapeake Bay. Taking a conservative wind speed of 25 knots gives a wave height of 4.4 feet at a period of 4.5 seconds. These winds are fairly frequent and usually are not accompanied by significant set-up. This wave would not have significant affect on large carriers but would affect the ability to control dredging tolerance. Long period ocean waves are considered significant but were not analyized in this report.

A 50 foot ~~channel~~ project designed for sheltered bay and harbor areas would probably have to be deepened due to differences in tide and wind. These differences might be quantified as shown in Table 8.

Table 8. Quantified design parameters for advance engineering of Hampton Roads and Lower Thimble Shoal Channel

Parameter	Hampton Road	Lower Thimble Shoal
Basic Project Depth	50 feet	50.0 feet
Allowance for Tide @ Cape Henry	——	0.3 feet
Pitch, roll, or heave for ocean swell	——	not analyized
Squat	——	——
Additional Safety Clearance		1.0 estimate
Advance Maintenance Dredging	——	——
Additional dredging tolerance	——	2.2 feet
Suggested minimum ~~additional~~ dredging depth for Thimble Shoal Channel in proximity of Cape Henry		53.5 feet

A similar analysis could be made for a 55 foot Project Depth however it appears conclusive that the minimum project being considered should provide considerable material availability in the lower Thimble Shoal Channel. It also shows that selection of a 55 foot dredging depth is realistic in answering the remaining questions.

The 1983 cores show (Appendix A) one promising area for sand recovery in dredging to -55 MLW: the eastern one-forth of the Main Channel (Figure 2). There, 6 cores indicate that uppermost material is about 2.2 million cubic yards of quartz sand typically 1/4 millimeter in diameter (Figure 3). Slight overdredging will not notably change characteristics of recovered material, but will yield and additional 0.5 million cubic yards per vertical foot.

Within the Fort Story study area, shore erosion is marked over the eastern half, and composite representations of sand-size distribution there closely resemble available borrow material (Figure 12). Quantitative procedures for estimating fill suitability (Table 6) show channel borrow sands to be about ideal according to the preferred composite (FSB) based on 9 samples from the native beach, but perhaps only "usable" according to another composite (FSA) giving even weight to all 20 samples from the active beach along profiles 9 through 16. The center of the borrow area in eastern Thimble Shoal Channel is three miles from the eroded Fort Story beach.

Preliminary design recommendations based on available evidence (Appendix D) include setting the berm elevation at +7 MLW and assuming the seaward fill slope at 1 on 15. Placing one million cubic yards along 6000 feet of shoreline should result in minimum berm widths of about 200 feet after profile adjustment to wave action (Figure 13). Available data do not permit quantitative estimates of fill durability, but appreciable residence time might be expected: placed sand appears to be of suitable size characteristics and subject only to moderate littoral forces driving it alongshore to the west. These judgements proceed from inferences about local transport patterns sketched in Figure 11: localized Fort Story beach erosion is associated with decreased supply of littoral drift from the Atlantic coast, due to wave and ebb-tidal currents having caused an extensive shoal to form slightly offshore of Fort Story's eastern boundary (Figure 10).

Sand Stockpiling at five sites was evaluated with limited data. Indications are that using all suggested sites, approximately 2.5 million cubic yards could be stored for future use. All areas are vegatated to some degree with Site D being the most densely populated with pine.

The above conclusions are best estimates from available data. Major work which needs to be accomplished prior to design are:

1. Sediment Sizes. A fully adquate composite representation of native sand requires a better balanced sampling plan. Needed samples are from +5, 0, -5, -10, and -15 feet MLW along several profiles at different times of the year. Such data will permit formation of a composite reflecting textural variability due to seasonal and water depth effects.

2. *Seasonal Profile variations. Repeated profile* surveys at different times of the year indicate beach section changes and limiting depths changes. At the minimum, expected variation along the shoreline and in time require bimonthly data along lines 10, 12, 13 and 15. (This measurement plan will suffice for sediment samples mentioned above.) Such data will permit firm final designs for fill sections. Since shoreline data gathered for this study was relative in location, a more thorough system should be devised to control and document the work. Accurate permanent baselines and benchmarks should be integrated with the Post grid which is the Virginia State Grid, South Zone. Elevation data should continue to be related to the Mean Low Water Datum.

3. Longshore Geometry. Better definition of the existing shore will be necessary for fill design in plan view and accurate volume computations. A sufficient, one-time survey might cover from wading depth through the backshore (MLW to +8 feet) at about 100-foot intervals along the reach to be filled.

Structures, outfalls and other features should be mapped. This work should also be controlled as described in 2 above.

4. Processes. Minimum further study of processes must include additional drogue measurements of tidal currents between lines 4 and 16 at Fort Story. Also needed are photographs of wave patterns during bay and ocean storms. Such data will contribute to improved knowledge of important coastal processes, to estimation of longshore transport rates, and to improved fill geometry.

5. Stockpiling. Sites selected for stockpiling need to be mapped at 1"=100' scale. This mapping might be performed by aerial photogrammetry however experience in mapping beach areas at Fort Story by this means indicates considerable field checking would be required (Holton, personal experience, 1975). In addition, Sites D & E are sufficiently vegatated to limit use of aerial methods.

Besides the field investigations outlined, further office analysis and literature review of Cape Henry processes is needed.

A final recommendation is to develop better knowledge of the borrow material extent and characteristics. The designated borrow area includes only 6 of the 1983 cores, so that each of 6 cores here represent about 0.1 square miles. In addition, several sand layers within the 6 cores were not defined by samples. Three levels of remedial study are: Obtain sieve analyses of additional samples from 1983 cores, so that each sedimentary strata is represented in the borrow material composite; integrate 1983 cored data with the several previous geophysical data collections in eastern Thimble Shoal Channel, to generate a coherent isopach map of the designated borrow area; and initiate additional coring on a closer grid in and around the borrow area, to resolve remaining uncertainties and determine advisable borrow limits

more precisely. This information will be particularly important in planning the material removal and evaluating different dredge plants.

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APPENDIX A

BOTTOM MATERIALS IN THIMBLE SHOAL CHANNEL

Thimble Shoal Channel extends for 9.9 nautical miles, with its eastern end near the main entrance to Chesapeake Bay, just north of Cape Henry, and its western end near the entrance to Hampton Roads. The authorized project presently consists of a main channel 1000 feet wide with nominal water depth of 45 feet MLW, and flanking auxiliary channels, each 450 feet wide with nominal water depth of 32 feet MLW. The feasibility of using bottom materials in Thimble Shoal Channel as fill for local beaches is to be assessed, in case authorization is obtained for deepening these navigation channels. The topics addressed here are the locations, amounts, and composite characteristics of possibly suitable channel sands.

Our conclusions contradict a statement from a 1982 Norfolk District report that says "Suitable sand for beach nourishment was not detected in Thimble Shoal Channel". That report considered nourishing beaches along the Ocean View section of Norfolk, Virginia, and the judg~~e~~ment about channel material was based on eight vibratory cores taken in 1980. Only one of those cores was located in the eastern half of Thimble Shoal Channel, where six 1983 cores with closer spacing indicate that useable beach fill might be obtained from an extensive surface layer.

The 42 locations of 1983 cores are displayed in Figure A1, along with a greatly simplified summary of the uppermost material types within the present bottom. This classification of channel material is extracted from core logs and considers only material above -55 feet MLW; a second type of

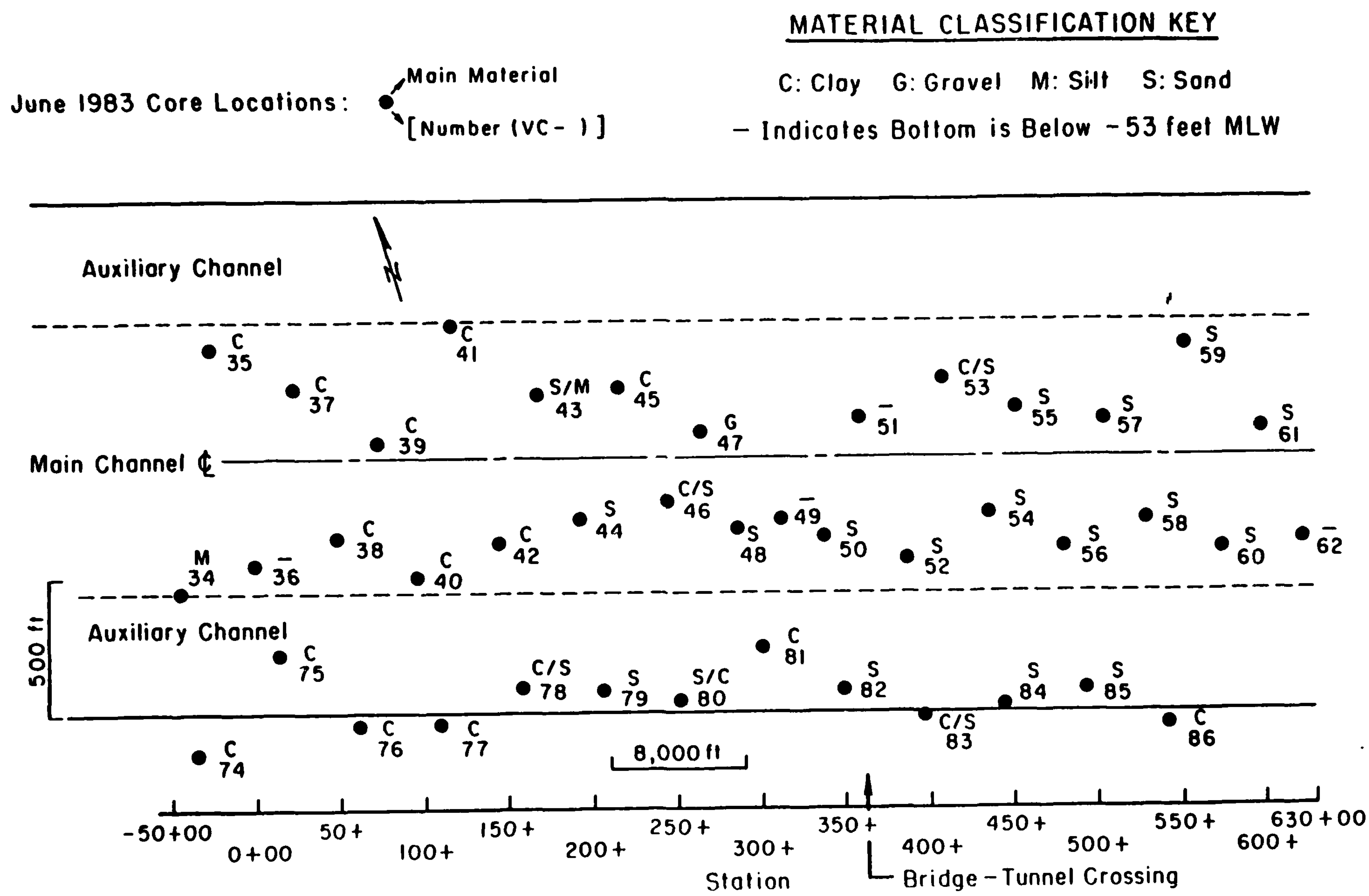

Figure A1. SUMMARY OF MATERIALS WITHIN THIMBLE SHOAL CHANNEL

material is indicated on Figure A1 if it represents more than 25 percent of the core length above -55 feet MLW. Fine sediments (clay and silt) are predominant, but sands occur over an extensive and contiguous area: the eastern one-fourth of the main channel. In the adjacent auxiliary channels, a sand bottom may also occur, but these regions appear less likely as potential borrow because depths are usually in excess of 42 feet which makes further dredging unlikely.

The important cores are the 1983 cores numbered 56 through 61. Table A1 summarizes computations based on available sediment analyses which provide the grain size distribution in Figure 3; this is a representative composite for the designated borrow area extending approximately between Thimble Shoal Channel Stations 465+00 and 610+00, across the entire main channel. Granting the simplifying assumptions explained in Table A1, the volume of fine/medium sand available above -55 feet MLW is about 2.2 million cubic yards. Based on the core descriptions, slight overdredging would not appreciably change composite borrow characteristics in this region; on the other hand, negligibly little material is available above -52 feet MLW. If the borrow area considered were extended westward to Station 425+00 in the main channel, available material above -55 feet MLW approaches 3.0 million cubic yards and the calculated composite becomes appreciably coarser, but overdredging would provide undesirable silt and clay in the region of the extension.

TABLE A1 - COMPUTATIONS YIELDING COMPOSITE GRAIN-SIZE DISTRIBUTION FOR POTENTIAL BORROW MATERIAL IN EASTERN THIMBLE SHOAL CHANNEL.

Information on the sub-bottom character of Thimble Shoal Channel includes log sheets classifying separate strata and describing the vertical variations in appearance within each core together with sand gradation curves for samples from selected segments. The recorded water depth at the location of each core ties elevations within each core to a horizontal datum-plane, e.g., MLW.

For present purposes a summary of this information is provided in the following way: separate strata are listed by vertical extent and the letters describing the material according to the Unified Soil Classification System, with the uppermost stratum at the top of the list. A horizontal line shows the location of (-55 feet) elevation within the core, and the location and I.D. of sediment samples are indicated. The highest parts of cores VC54 through VC61 from the eastern part of the (main) Thimble Shoal Channel can then be described as follows. [The datum plane used here is that from the blueprint displaying core locations and characteristics.]

VC54

	(SP)	0.8'
	(GP)	0.2'
Sample A →	(SP)	2.1'
	(SP-CH)	0.3'
	(GP)	0.5'
	(SP)	0.2'
	(CL)	7.9'

VC55

A →	(SP)	4.6'
	(GP)	0.8'
	(ML)	0.2'
		14.4' (core bottom)

VC56

	(SP)	2.0'	I
A →	(SP-SM)	1.2'	II
	(SP)	1.1'	III
		6.6'	

VC57

A →	(SP)	3.9'	I
		0.9'	
B →	(SM)	3.2'	
	(SP-SM)	0.5'	
	(SM)	0.6'	

VC58

A →	(SP)	3.0'	I
		7.1'	

VC59

A →	(SP)	3.8'	I
		12.2'	

VC60

	(SM)	0.7'	I
A →	(SP)	4.7'	II
		0.4'	
	(CH)	0.4'	
	(SP)	0.6'	
	(CH)	0.2'	
	(SP)	0.5'	
	(CH)	0.5'	
	(SP)	2.8'	

VC61

	(SP-SM)	3.7'	I
A →	(SM)	0.7'	II
		3.6'	
	(CL)	5.8'	

(Water depth is in excess of 59 feet at the eastern-most core, VC62, which contains clay

Because -55 feet is a somewhat arbitrary limit to dredging, it appears that consideration of a borrow area extending from VC56 to VC61 would be most appropriate: appreciable overdredging in the region of cores VC54/55 will recover predominantly undesirable fine material, silt (M) and clay (C

To assemble a meaningful composite grain-size distribution, the available sample analyses indicated above are utilized both for the core strata of which they are directly or indirectly representative. The following computation procedure averages over gaps in firm data on bottom materials, e.g. the lack of grain-size distributions for the top layers in VC56, VC60 and VC61, as indicated above.

For VC56 through VC61, all materials above -55 ft are classified as predominantly sand. In those 24.8 feet of core, the breakdown by basic classification is

(SP) : 74.6 % - ; (SP-SM): 19.8 % - ; (SM) : 5.6 %
18.5 ft in 6 layers ; 4.9 ft in 2 layers ; 1.4 ft in 2 layers

Directly representative grain-size distributions are available for 3 of the 10 layers

56 II (SP-SM) ; 57 I (SP) ; 60 II (SP) ; as indicated above.

No grain-size distribution is available for sample A from 61 II (SM), because 35% fines evidently make it unsuitable for analysis. The only viable option in representing the two SM layers in these cores is to adopt the available grain size distribution from Sample B of VC 57. That material ("fn sand little silt gray N/P moist") may be representative in a balanced way of the combined short spans in
60 I ("fn sand little silt tr. med sand gray N/P moist")
and
61 II ("fn sand some silt tr. pt. gray N/P moist")

Of the two (SP-SM) layers, there is a close match in descriptions between 56 II and 61 I, so the former grain-size distribution can be adopted for the latter, with confidence.

Uncertainties remain about four SP layers:
- there is an exact match of descriptions between 56 I and 57 I, so the latter results can be taken to represent the former, with confidence.
- 56 III seems unlike any other sand mentioned on the log sheets; this is the only instance of orange color, so this layer remains undefined in so far as exact grain-size distribution
- the log sheet for VC 59 indicates that results for Sample A should be exactly representative of layer 59 I
- the log sheet for VC 58 indicates that there may be some uncertainty whether results for Sample A are truly representative of layer 58 I; although the (SP) layer is nominally continuous, there are some distinctions in the detailed description. However, there seems to be no viable alternative, so the results will be adopted for 58 I.

The judgment used in making choices of adequate substitute data to describe unknown material characteristics must be treated as firm; to counteract the uncertain description of 58 I, for example, by giving it less weight in final computations, would inappropriately affect the amount of sediment in that layer. Appropriate weighting factors to be applied are to represent the individual layer thicknesses relative to the total core thickness.

[Note that the uncertainties associated with (SM) and (SP-SM) layers could not be counteracted, because each must be based on a single grain-size distribution to yield fixed weights, namely 5.6 % and 19.8 %, in the total composite distribution.]

Recorded Percents Coarser by Weight in Sediment Samples Used to Form Composite

LSM3

Sieve Number:	4	10	20	40	50	70	100	140	200	Fines	Sum
(SM) 57B {60I; 61II}: 5.6% total weight	—	—	—	—	—	0.01	0.08	0.47	0.28	0.16	1.00
(SP-SM) 56A (56II; 61I): 19.8% total weight	—	—	—	0.02	0.02	0.23	0.34	0.175	0.105	0.11	1.00
(SP) {74.6% total weight}											
57A (56I, 57I): 25.3%	—	—	—	0.01	0.02	0.235	0.50	0.125	0.08	0.03	1.00
58A (58I): 12.85%	—	—	0.03	0.24	0.34	0.28	0.05	0.02	0.01	0.03	1.00
59A (59I): 16.3%	—	0.01	0.03	0.22	0.33	0.34	0.03	0.01	0.01	0.02	1.00
60A (60II): 20.15%	0.01	0.02	0.15	0.38	0.22	0.13	0.04	0.01	—	0.04	1.00
Composite:	0.0002	0.0057	0.0390	0.1498	0.1508	0.2232	0.2177	0.0988	0.0596	0.0535	
{cumulative (rounded)}		0.006	0.045	0.195	0.346	0.569	0.787	0.886	0.946	1.000	

Here $D_{16} = 0.47$ mm $(1.09\,\phi)$, $D_{50} = 0.233$ mm $(2.10\,\phi)$, $D_{84} = 0.124$ mm $(3.01\,\phi)$

These values are interpolated between the known points of the composite computed above, using log D (phi) - probability paper, i.e., presuming the size distribution is normal.

This composite is meant to represent the 1000-ft main channel width, about from Station 465+00 to 610+00, a distance of 14,500 feet and an average deposit thickness of (24.8/6) feet: 2,220,000 yd^3

RJH
29 Dec 83
30 Jan 84

APPENDIX B

SAND CHARACTERISTICS ON FORT STORY BEACHES

The following plots display median and representative extreme sediment diameters: D_{50}, D_{16}, and D_{84}. These have been interpolated from results of sieve analyses (half-phi intervals). Phi size is plotted against location along the Fort Story coast, for each nominally comparable sampling site. Figures B1-B5 pertain to samples from dune, berm, foreshore, low-tide terrace, and offshore, respestively.

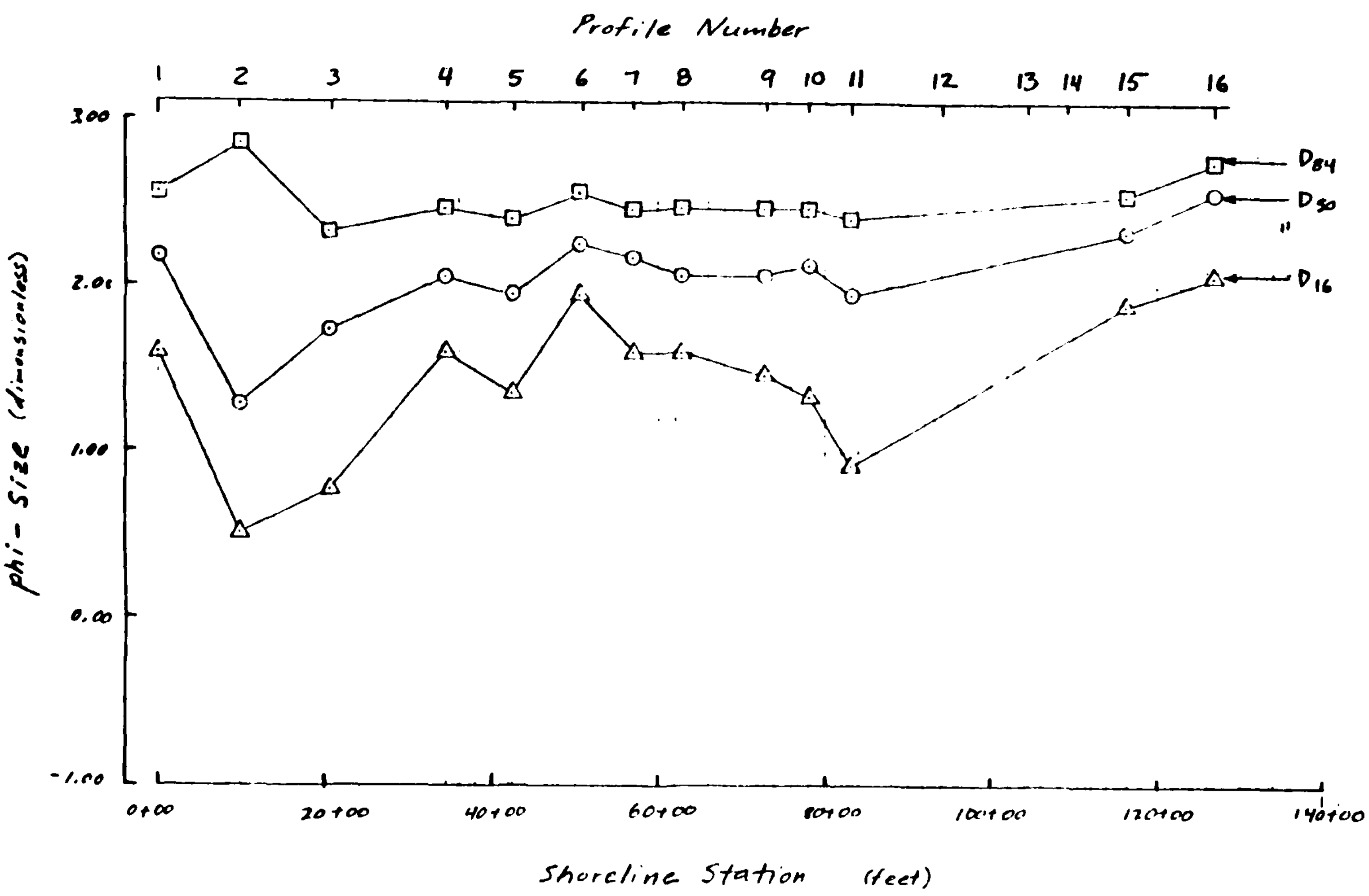

FIGURE B1. DUNE SAMPLES (A) AT FORT STORY

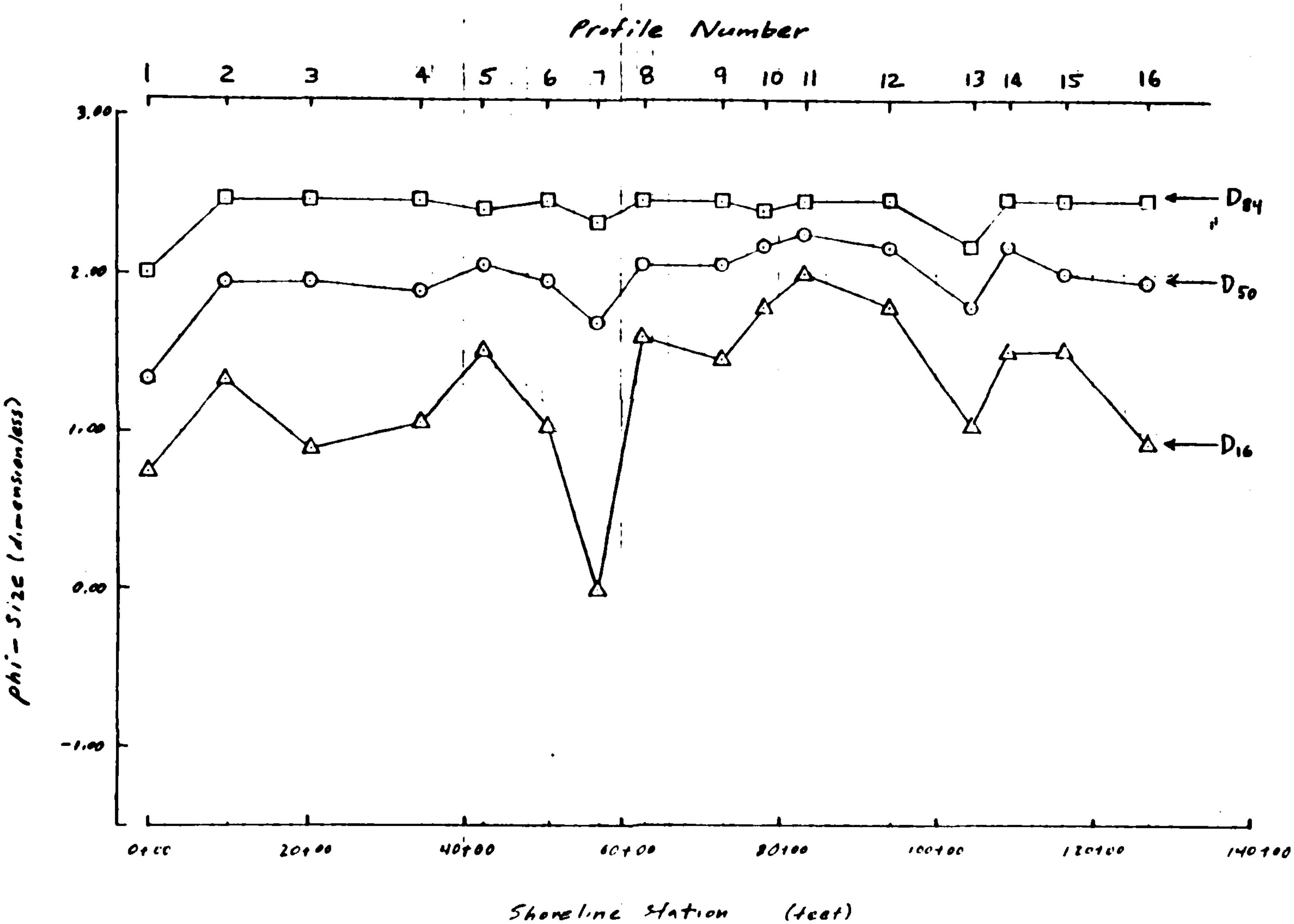

FIGURE B2. BERM SAMPLES (B) AT FORT STORY

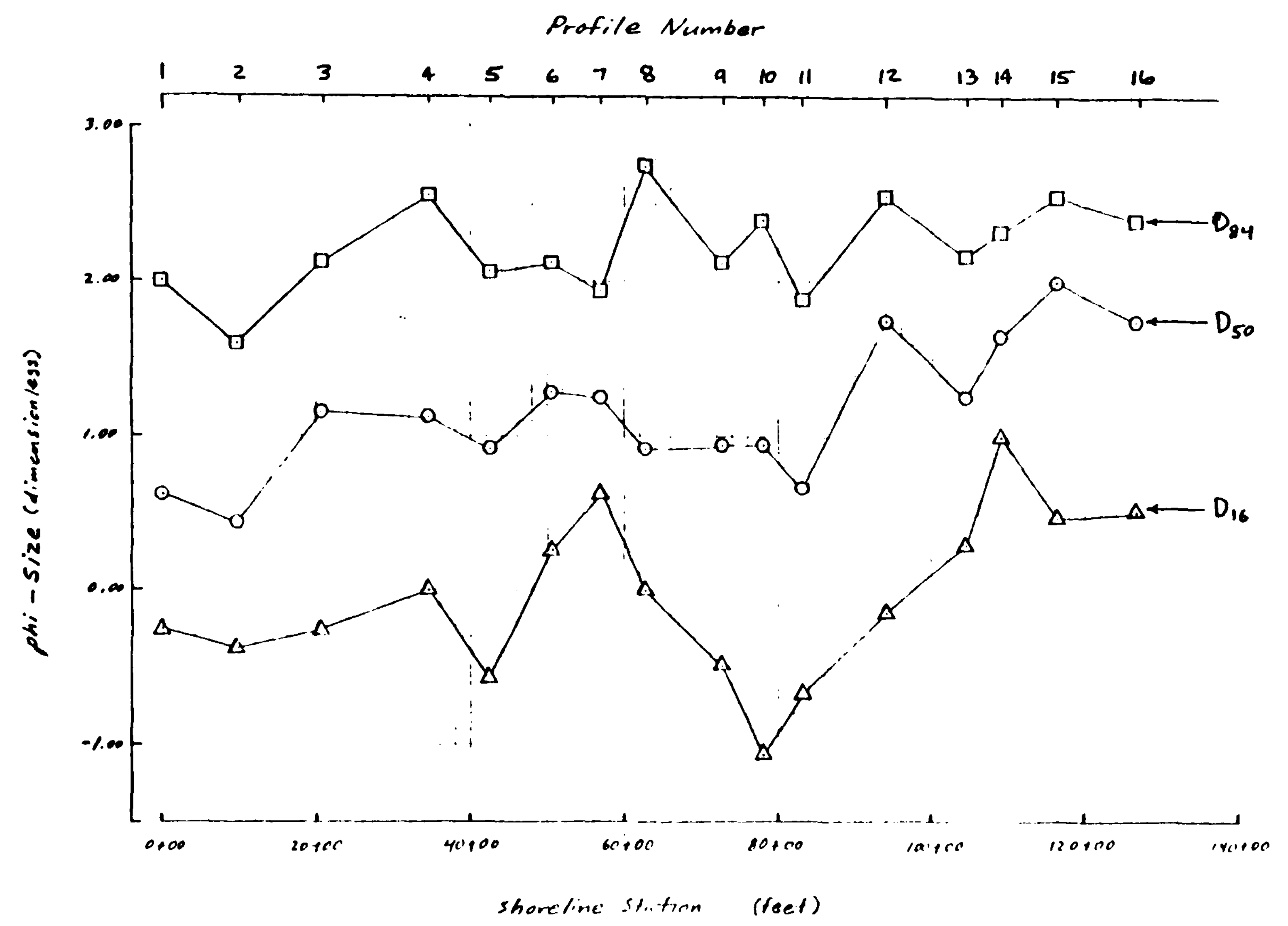

FIGURE 83. FORESHORE SAMPLES (c) AT FORT STORY

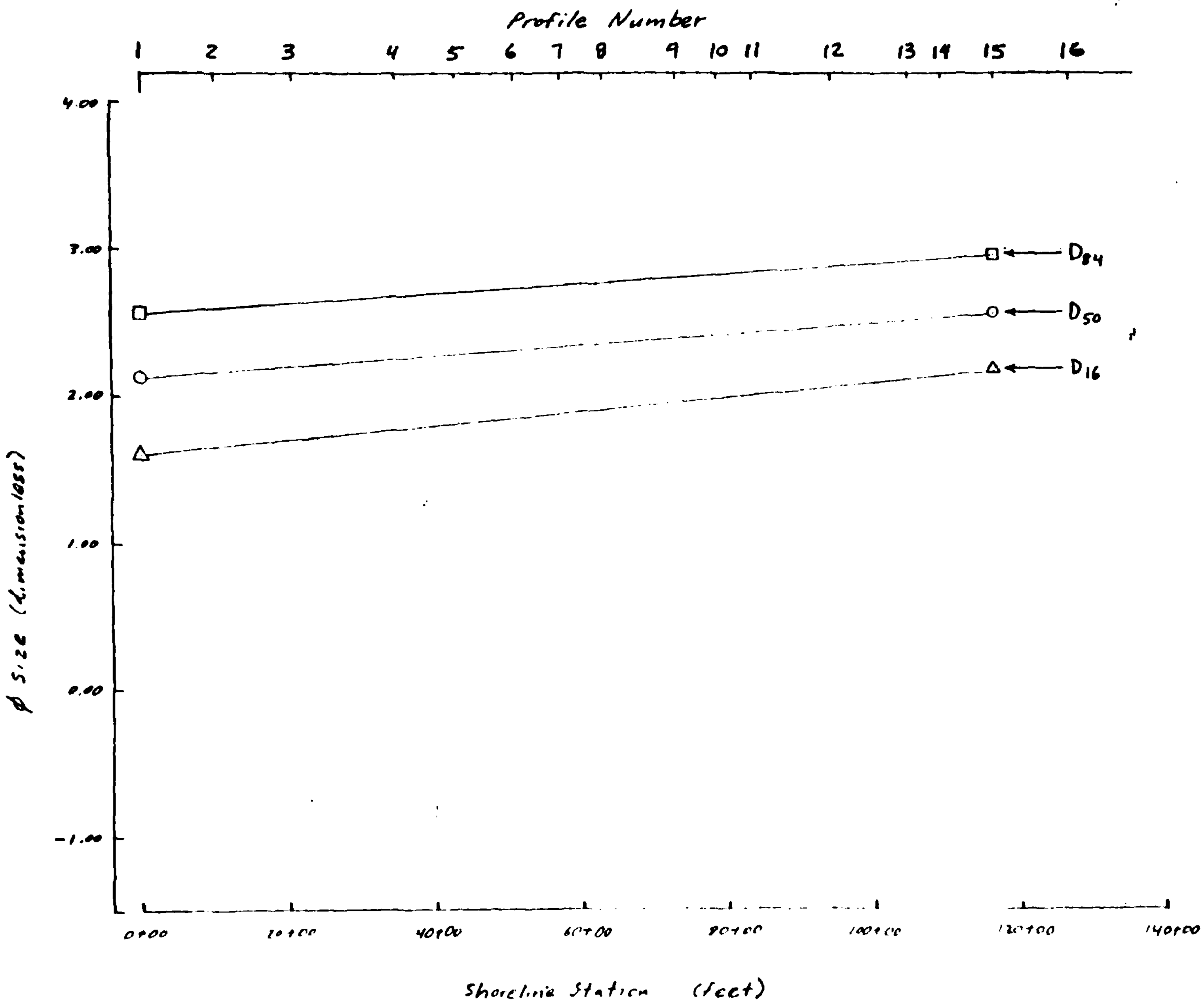

FIGURE B4. LOW-TIDE TERRACE SAMPLES (D) AT FORT STORY

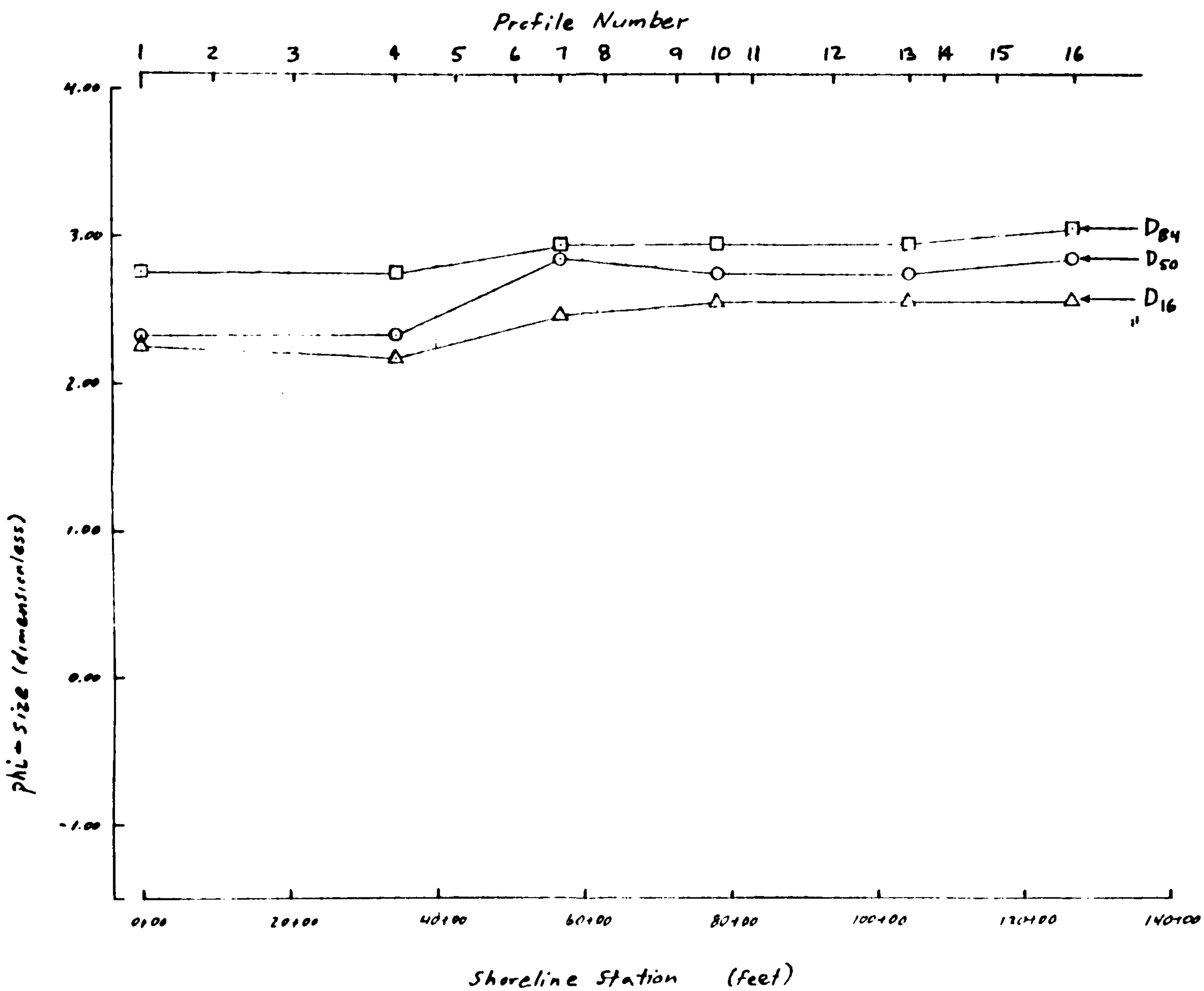

FIGURE B5. OFFSHORE SAMPLES AT FORT STORY

APPENDIX C

COMPUTATIONS OF WAVES FROM CHESAPEAKE BAY

This section documents the calculations performed in the analysis of exposure at the Fort Story site to waves generated in Chesapeake Bay. The product of such calculations are forecast values of significant wave height and period, which may be of use in prediction of littoral transport and in design of beach fill geometry. The immediate purpose of this effort was to compare the wave climate of the Fort Story site with that of the gage location on the Chesapeake Bay Bridge-Tunnel, to be able to assess the appropriateness of taking observed wave data at the Bridge-Tunnel as characteristic of the Fort Story site also.

Procedures used are from Sections 3.43 and 3.61 of the 1977 edition of the Shore Protection Manual.

Effective Fetch Calculations. In an enclosed bay with an irregular shoreline, the fetch length used in shallow water wave forecasting models should be an effective fetch, which accounts for the wave growth-limiting effects of the surrounding shoreline. To compute an effective fetch, one must first construct a diagram such as Figure C1, which is for a shoreline point representative of the Fort Story site. Figure C2 is for the wind wave gage location on the south island of the Chesapeake Bay Bridge-Tunnel. Both figures were constructed with the orientation of the radials positioned so as to obtain the maximum effective fetch. Ordinarily one would also be interested in positioning the

FIGURE C1. EFFECTIVE FETCH
FORT STORY, VIRGINIA

FIGURE C2. EFFECTIVE FETCH-CHESAPEAKE BAY BRIDGE-TUNNEL GAGE LOCATION

central radial parallel to the direction of maximum winds for a separate effective fetch calculation; however, in the present case the orientation would not be substantially changed.

Tables C1 and C2 show the computation procedure for the effective fetches of the two above-mentioned locations. Note, although the format of the tables differs slightly, the computation procedure is exactly the same. Also, the resulting effective fetch length are within 5% of each other.

Figure C3 shows a working diagram used in estimating the average depth of the Chesapeake Bay along the wave generating fetches. The procedure entailed selecting representative soundings from the nautical chart at 5 evenly spaced cross-section locations along the central radial and the adjacent radial on either side, then computing the mean depth of all the selected soundings. The resulting depth is 37 feet MLW for Fort Story and 35 feet MLW for the Bridge-Tunnel.

Tables C3 and C4 show the wave forecast results using the Shallow Water Wave Tables from the Shore Protection Manual. In Table C3 a range of straight-line (rather than effective) fetch lengths were used, to gain a feel for the sensitivity of the prediction to fetch length. In Table C4, the model's sensitivity to the average depth was tested. The final forecasts were made after a review of the results of this appendix. Table 4 presents the forecasts in the main body of the report.

α	$\cos\alpha$	r	X_i	$X_i \cos\alpha$
42	.743	6.2	4.61	3.42
36	.809	9.8	7.93	6.41
30	.866	9.2	7.97	6.90
24	.914	11.0	10.05	9.19
18	.951	10.3	9.80	9.32
12	.978	11.7	11.44	11.19
6	.995	19.2	19.10	19.01
0	1.000	30.2	30.20	30.20
6	.995	23.1	22.98	22.87
12	.978	5.5	5.38	5.26
18	.951	4.7	4.47	4.25
24	.914	3.4	3.11	2.84
30	.866	3.6	3.12	2.70
36	.809	4.5	3.64	2.94
42	.743	6.8	5.05	3.75
$\Sigma =$	13.512			140.25

$$F_{eff} = \frac{\Sigma X_i \cos\alpha}{\Sigma \cos\alpha}$$

$$= \frac{140.25}{13.512} = 10.38 \text{ in.}$$

(at a scale of 1:200,000
1 in. = 3.16 statute miles)

$$F_{eff} = 10.38 \times 3.16$$

$$= \boxed{32.8 \text{ miles}}$$

EFFECTIVE FETCH CALCULATION FOR FORT STORY, VIRGINIA
TABLE C1.

α	$\cos^2\alpha$	r	$X_i \cos\alpha$
42	.552	3.8	2.10
36	.655	7.3	4.78
30	.750	7.9	5.93
24	.835	10.1	8.43
18	.904	7.8	7.05
12	.957	9.1	8.71
6	.990	18.7	18.51
0	1.000	29.1	29.10
6	.990	21.4	21.19
12	.957	25.8	24.69
18	.904	6.3	5.70
24	.835	(blocked by Bridge-Tunnel)	
30	.750	4.9	3.68
36	.655	4.5	2.95
42	.552	3.7	2.04
$\Sigma =$	13.512		144.86

$$F_{eff} = \frac{\Sigma X_i \cos\alpha}{\Sigma \cos\alpha} = \frac{144.86}{13.512} = 10.72 \text{ in.}$$

(at a scale of 1:200,000 1 in. = 3.16 statute miles)

$$F_{eff} = 10.72 \times 3.16 = \boxed{33.9 \text{ miles}}$$

EFFECTIVE FETCH CALCULATION FOR CHESAPEAKE BAY BRIDGE-TUNNEL GAGE LOCATION

TABLE C2.

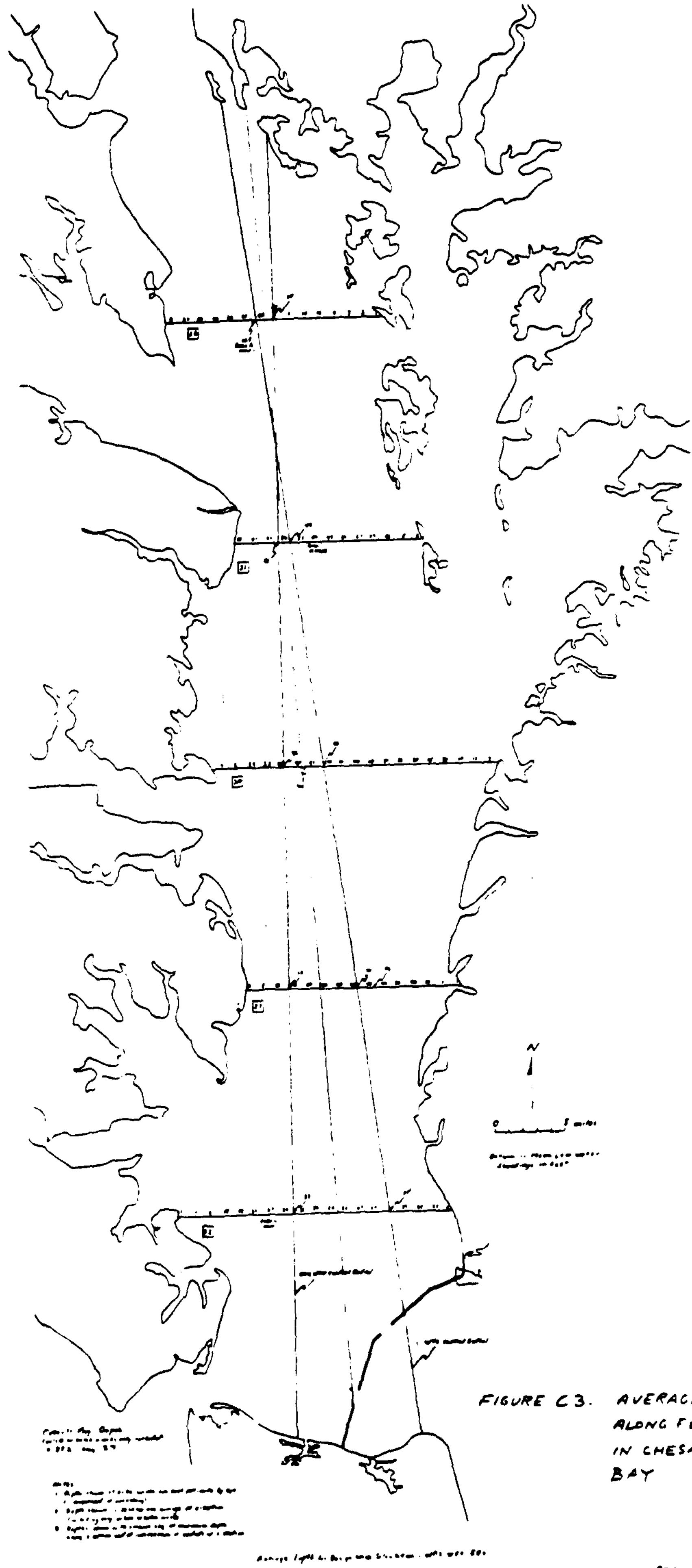

FIGURE C3. AVERAGE DEPTH ALONG FETCHES IN CHESAPEAKE BAY

WIND DIRECTION / FETCH LENGTH (ft)	WIND SPEED (mph)					
	20		30		45	
	H (ft)	T (s)	H (ft)	T (s)	H (ft)	T (s)
WNW/ 83,000	2.6	3.3	3.9	4.2	5.8	5.0
NW/ 145,000	3.0	3.7	4.6	4.5	6.6	5.4
NNW/ 170,000	3.2	3.8	4.8	4.6	6.8	5.5
N/ 120,000	2.9	3.6	4.3	4.3	6.3	5.3
NNE/ 60,000	2.5	3.2	3.5	3.8	5.2	4.7
NE/ (not a shallow fetch)	—	—	—	—	—	—

WAVE FORECASTS FOR FORT STORY, VIRGINIA, USING STRAIGHT-LINE FETCHES AND AN AVERAGE CONSTANT DEPTH OF 40 FEET:
HEIGHT AND PERIOD OF SIGNIFICANT WAVE

TABLE C3.

AVG. DEPTH (ft)	WIND SPEED (mph)					
	20		30		45	
	H (ft)	T (s)	H (ft)	T (s)	H (ft)	T (s)
20	2.6	3.5	3.6	4.2	4.7	5.0
25	2.8	3.6	4.0	4.3	5.7	5.2
30	3.0	3.7	4.3	4.5	5.9	5.3
35	3.1	3.7	4.6	4.6	6.4	5.5
* 35	3.3	3.8	4.8	4.7	6.6	5.7
40	3.2	3.8	4.8	4.7	6.8	5.6
* 40	3.4	3.9	5.0	4.8	7.1	5.8
45	3.2	3.8	4.9	4.7	7.0	5.7

* Effective fetch of 225,000 feet used

NOTE: The median windspeed, 10 Knots, results in a wave forecast of H = 1.7 feet, T = 2.75 seconds

WAVE FORECASTS FOR CHESAPEAKE BAY BRIDGE-TUNNEL, USING AN EFFECTIVE FETCH OF 180,000 FEET: HEIGHT AND PERIOD OF SIGNIFICANT WAVE

TABLE C4.

APPENDIX D

DESIGN OF BEACH FILL AT FORT STORY

The purpose of this section is to present the preliminary design of a beach fill at Fort Story, Virginia, and make suggestions pertinent to the fill construction. Considerations in development of the design are outlined also. Figure 13 shows characteristics of the design beach fill in profile view.

Cross Sectional Shape Characteristics. As can be seen in Figure 13, the design fill is defined by the following dimensions and angles:

1. Berm elevation
2. Berm width
3. Foreshore slopes

Ordinarily, these parameters exist on natural beaches in a relationship which is determined by the wave climate and sand grain characteristics. At times it is possible to label a beach as stable, eroding, or accreting, by examination of the shape of the beach profile plot resulting from a survey extending from the dune or upland boundary to a distance offshore corresponding to the limit depth of littoral action. Artificial beaches are ordinarily designed to replicate the natural beach's function. Thus, the fundamental bases for a fill design are appropriate natural beach paramenters.

The following sections address the development of design fill elements.

Berm Elevation. Although the berm elevations of the nearby natural beach profiles were used as the primary basis for the selection of the design elevation of 7 feet above MLW, several other approaches were considered as a check on the reasonableness of the selected value.

An examination of the measured beach profile No. 5, as seen in Figure 7A, reveals a pronounced break in slope at approximately 7 feet elevation above MLW. Note that profiles 1 and 4 also have prominent berms at about the same elevation, and profiles 2 and 3 also show some evident berm formation within about a one foot range of that in profile 5. To the east, most profiles are substantially reduced in beach width, and significant berm formations are difficult to detect. However, on profiles 6, 10, and 14 through 16, there are apparent berms at elevations ranging from 5 feet to 9 feet. Since the surveys were done within a few days of each other, it is likely that the berms are all representative of the action of the same storm event. If the shapes of the measured profiles can be considered representative of the typical long-term coastal exposure for Fort Story, then the selected 7 foot elevation should be appropriate.

For comparison, the berm elevation selected in a beach fill design in the nearby, somewhat less exposed Willoughby Spit area, was 5 feet above MLW (USAE, Norfolk District, 1982). According to that report, the intention was to select an elevation which "would best preserve and closely resemble the existing beach contour." On the other hand, by comparison to the east, typical measured profiles at profile line 1, in a report on beach erosion and accretion at Virginia Beach (Goldsmith et al., 1977), show a pronounced upper berm at about 8.7 feet above MLW.

This report does not consider the effect of storm surge explicitly, and the proposed design is not intended to serve primarily as storm flooding protection. However, to help put a perspective on the selected berm height, the aforementioned Willoughby Spit report has mention of high tides in excess of 6 feet above MLW, for the northeaster of 27 October - 8 November 1977, and slightly lower tides for the 26-27 April 1978 northeaster. Also mentioned is a maximum still water level of 8.3 feet above MLW for the 7 March 1962 storm.

Also considered in selection of berm height were wave runup estimates using formulas for manmade structures. Scale model experiments formed the basis for such estimation procedures. The estimates resulting from application of the procedures are not included herein, because it is felt that further refinements, beyond the scope of the present study, are necessary before such procedures will produce reliable information for this beach fill application.

Berm Width. Although the term "berm width" is commonly used in beach fill design, it is important to make the distinction between the width of berm immediately following construction and the eventual width after redistribution of the fill material. One must consider the fact that practicalities of beach fill construction require a relatively steep slope to the face of the beach fill between the berm elevation and the toe of the fill. The effect of the subsequent wave action is to spread the fill out to the seaward limit of littoral action, and consequently, erode away the berm, until the profile has attained an equilibrium shape essentially parallel to the pre-existing natural profile.

As used in this report, the design berm width is the total width of berm on the eventual profile. Selection of a design berm width is influenced by non-engineering and economic considerations such as recreational benefits to be derived and design life of the fill. In the current situation where the primary purpose of the fill is to put dredged material to a beneficial use, and the supply of material is not a limiting factor, then a maximum berm width is desirable.

From a scrutiny of the measured profiles and field observations, it was decided that profiles 1 through 5 have adequate berms already. In the remaining profiles these are varying widths of berm, from essentially no berm to about 100 feet. It was somewhat arbitrarily decided that a minimum berm width of 200 feet, which matches that found on profile 5, would be appropriate. Then a check on the practicality of the 200 foot number was made. The volume of fill required per unit length of beach to be filled is represented by the area between the existing profile and the eventual profile. The eventual profile is simply a horizontal displacement of the existing profile, by a distance equal to the difference between the design minimum berm width (200 feet) and the existing berm width. In the extreme case where there is no existing berm, the eventual profile is displaced 200 feet seaward, and the distance A-A'' on the immediate profile of Figure 13 is at a maximum. The area between the immediate profile and the existing profile is equal to the area between the design profile and the existing profile (the intermediate post-fill profile shows a more realistic shape for the fill section). For the reasonableness calculation, the shapes for the existing, design, and immediate profiles of Figure 13 were used, assuming no existing berm. The resulting distance A-A'' is

approximately 450 feet, which is considered within the range of acceptability should the redistribution of the fill proceed very slowly.

Foreshore Slopes. The existing profile shown on Figure 13 has a shape below Mean Low Water typical of the stretch of beach between profiles 8 and 16. The slopes and lengths represent an average of those profiles out to the seaward limit of littoral action, d_s = 17 feet MLW depth, as presented in the computations section of this report. Design profile slopes are the same as the existing profile for corresponding segments. The slope of the seaward toe of the fill is shown to be the same as that of the foreshore, 1 on 15, which was considered to be a reasonable approximation. In selecting the foreshore slope, the measured profiles were examined to see if any longshore trends were evident. There was great varition in the measured slopes, with no correlation to the expected trend of flatter slopes to the east due to predominance of large waves. An average slope would be somewhere between 1 on 13 and 1 on 20. Figure 4-32 of the Shore Protection Manual relates foreshore slopes to median grain size. A typical grain size for the borrow material is 0.25 mm, which corresponds to a slope of about 1 on 18 in Figure 4-32. It was felt that due to the winnowing effect of handling losses and the tendency for finer sizes to be distributed towards the seaward part of the profile, that a design foreshore slope of 1 on 15 would be reasonable.

Considerations in Fill Placement; Limitations of the Design Approach. A single set of values for berm elevation, berm width, and foreshore slopes are given in the preliminary design presented herein. This approach ignores the complexity and variability of the Cape Henry shoreline. It

would be preferable to vary the dimension and slopes of the design profile according to longshore variation in the wave climate and littoral transport characteristics. Also, there may be an interest in varying the design parameters according to other considerations such as sand stockpiling, increased erosion protection for structures, smoothing of crenulations in the shoreline, and recreation potential. The preliminary fill design is limited by the lack of measured profiles showing the seasonal variations in shape. Also, the current understanding of coastal processes around Cape Henry, particularly littoral transport rates and directions, is not considered to be sufficiently refined to be properly considered in the selection of design parameters. The effect of handling losses on the grain size distribution of the borrow material needs to be addressed also.